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ED&T 1541
project record report

AIRCRAFT SPRAY SYSTEMS

September, 1970

U.S. Department of Agriculture
Forest Service (Wash. D.C)
Equipment Development Center
Missoula, Montana

NATIONAL FOREST SYSTEM COOPERATIVE FORESTRY FORESTRY RESEARCH
FOREST SERVICE US DEPARTMENT OF AGRICULTURE

6192237

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PROJECT RECORD REPORT

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AIRCRAFT SPRAY SYSTEMS

September 1970

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PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

ABSTRACT

This report covers the development of an aircraft aerosol spray system for ultra low volume aerial spraying at large flow rates. Because of the use of an atomizing fluid with a high vapor pressure, it was necessary to use a pressurized system with an inert gas as a propellant. The system evolved to be very simple and easy to operate with high reliability since a pump and a pump power source is not required and with a pressurized tank, the contents can be unloaded rapidly through a small discharge duct. The system was designed to minimize leakage and proof tested to 150 psig. For this reason and because it is simple to operate, it is well liked by the pilots. Also, since it is not elaborate, it is easy to install in an airplane with very few modifications needed.

The system can also be used to dispense an insecticide solution by itself without an atomizing fluid. Used as a standard system it still retains the same advantages of being essentially leak proof, simple to operate, and highly reliable with rapid discharge of the tank contents.

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INTRODUCTION

This report covers nozzle testing and the design and development of aerial spray equipment by the Missoula Equipment Development Center for a 3-year period beginning in the fall of 1966. The Center was selected in 1965 by the Division of Forest Pest Control to support the Insecticide Evaluation Project by providing them with equipment as they requested. The criteria for the equipment discussed in this report was initiated by a memorandum (see appendix) from Dr. Arthur D. Moore, Project Leader of the Insecticide Evaluation Project, who specified a spray system that would produce droplets with a maximum size of 50 microns (0.00197 inches) in diameter. During the 1966 pilot tests in the Bitterroot National Forest[1/] it was found that 92% of the droplets observed on the spruce budworm were 21 to 31 microns in diameter.[2/]

It was determined that the small droplets are effective because they remained suspended in the atmosphere for a longer period of time and will drift with air currents and penetrate the foliage. The larger drops fall rapidly and either hit the ground directly or roll off the crowns of the trees to the ground. The chance of a large drop contacting a budworm is very remote.

At equal application rates, a system that produces droplets with a maximum size of 50 microns in diameter will yield a considerably higher density of droplets per volume of atmosphere than a system that produces drops with a maximum drop size of 400 to 300 microns in diameter. For example, one 400 micron drop is equal in volume to 512 50 micron drops, one 300 micron drop is equal in volume to 216 50 micron drops and one 200 micron drop is equal in volume to 64 50 micron drops.

A high density of small drops that remain suspended will result in an expansive distribution of insecticide which is still sufficiently concentrated through the foliage to have a high probability of contact with the insect. Therefore, the system is more efficient and can be used for lower volume applications which will reduce the amount of insecticide used and thus reduce the amount of contamination of the environment.

In addition to designing the spray system, Dr. Moore requested that MEDC provide all the hardware for the system and that Forest Service aircraft be used. On previous pilot tests, private spray equipped aircraft had been used. It was found that the average spray system on private aircraft

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1/ Department of Agriculture, Forest Service. Spruce Budworm Zectran Pilot Control Test, Missoula, Montana, Region 1, January 1968.

2/ HIMEL, CHESTER M., AND MOORE, ARTHUR D. Spray droplet size in the control of spruce budworm, boll weevil, bollworm, and cabbage looper. Journal of Economic Entomology, August 1969. pp. 916-918.

was poorly designed and fabricated, had numerous leaks, was not too reliable, and was contaminated with other insecticides. For example, during the 1966 pilot tests, one of the contract airplanes had several leaks in the system; as a result there was a high concentration of fumes in the airplane which gave both of the pilots severe headaches.

As drift is a problem with small drops, Dr. Moore planned to make use of air movement to transport the droplets through the foliage. He planned to dispense the insecticide solution in the bottom of a drainage just below a temperature inversion shortly before sunrise. As the sun rose, the solar radiation heated the ground, created air currents that flowed upward along the slopes carrying the droplets through the trees. Figures 1 and 2 illustrate this formation and the break-up of an inversion.

OBJECTIVES AND REQUIREMENTS

The objective of the program as outlined in the fall of 1966 was to develop a completely operational aerial spray system that produced drops all less than 50 microns in diameter, with an mmd (mass median diameter) of 20 microns or less. The system was to be used for the 1967 Zectran pilot test.[3/] Other requirements of the system were:

a. The insecticide to be used was Zectran[4/] with Dowanol[5/] DB as the carrier. (Dowanol DB was later changed to Dowanol TPM.)

b. The aircraft to be used were the Bell Helicopter at 50 mph and 4 gpm flow rate; Cessna 185 at 100 mph and 15 gpm flow rate; and the Douglas C-47 at 150 mph and 45 gpm flow rate. This required design and fabrication of three separate aerial spray systems.

c. Thermal generation could not be used because Zectran decomposes at temperatures above 160°C (320°F).

TEST PROCEDURES

Initially the mechanics of producing aerosol size drops did not seem too great; however, after many months of testing of standard spray nozzles it

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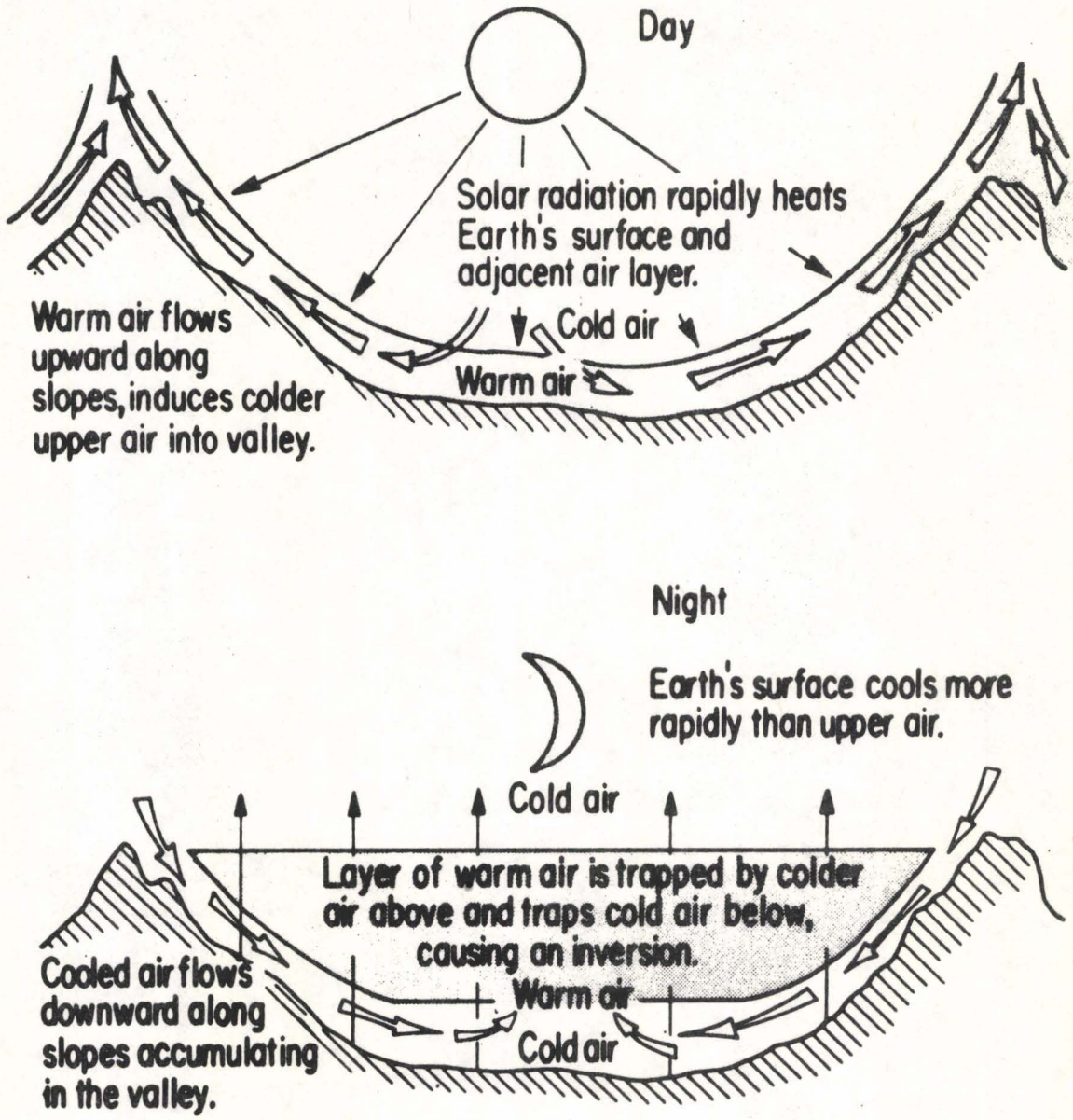
3/ Department of Agriculture, Forest Service. The 1967 Big Smoky Spruce Budworm Zectran Project, Tayton, Shag, Ogden, Utah, Region 4.

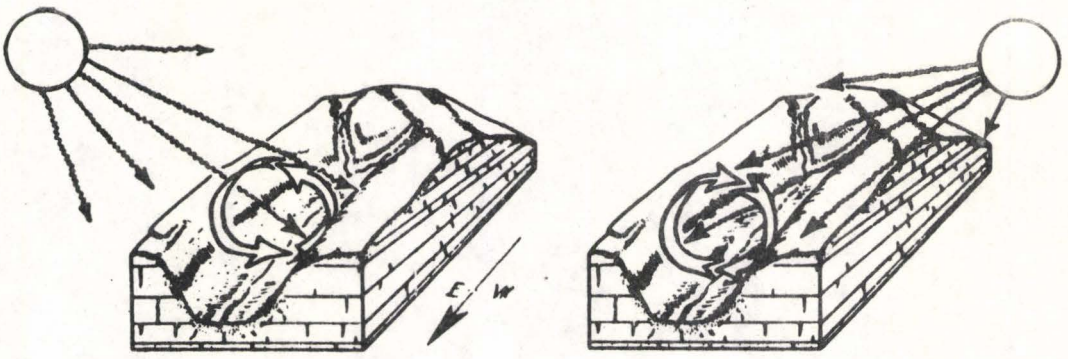
4/ ZECTRAN - Registered trademark of Dow Chemical Company for its organic carbamate compound.

5/ DOWANOL - Registered trademark of Dow Chemical Company for its Glycol Ethers.


Day
Solar radiation rapidly heats Earth's surface and adjacent air layer.
Warm air flows upward along slopes, induces colder upper air into valley.
Cold air
Warm air
Night
Earth's surface cools more rapidly than upper air.
Cold air
Layer of warm air is trapped by colder air above and traps cold air below, causing an inversion.
Cooled air flows downward along slopes accumulating in the valley.
Warm air
Cold air

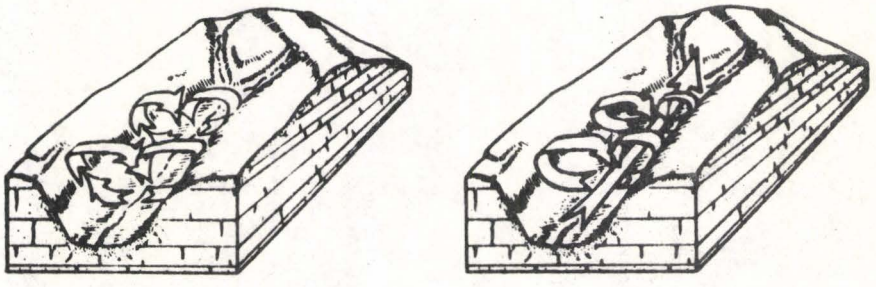
CAUSES OF TEMPERATURE INVERSION

FIGURE I



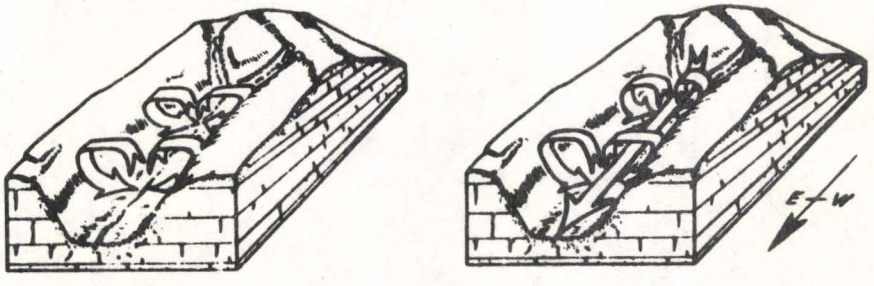
MORNING

EVENING



FORENOON

MIDDAY



LATE EVENING

MIDDLE OF NIGHT

AIR MOVEMENTS IN A VALLEY CREATED BY SOLAR RADIATION

FIGURE 2

soon became apparent that it was a problem that could not be solved very easily.

The nozzles were tested with the carrier fluid pressurized by nitrogen which was metered into the tank by a regulator valve that maintained the tank pressure within close limits. The nozzles were operated in an airstream at the same velocity as the aircraft, to duplicate the effects of air shear. After the liquid pressure and operation of a nozzle stabilized, sampling slides downstream of the nozzle were exposed to the spray for a given period of time (depending on the flow rate of the nozzle), and then covered. The nozzle was then shut off and removed from the airstream and the sampling slides taken to the laboratory. The slides were observed under a microscope and the largest drops recorded as the drop size for that nozzle under the set test conditions.

a. Equipment. A large engine driven centrifugal blower was used to produce the high velocity airstream. The velocity of the airstream was varied by adjusting the engine rpm, and the air velocity measured with a velometer.

b. Sampling Method. With the requirement to find a nozzle that produces droplets no larger than 50 microns in diameter, a simple sampling method was used in which only the larger droplets were measured. The drops were collected on magnesium oxide coated slides and with a microscope only the larger droplets were measured on each slide. The largest drop observed was recorded as the droplet size for each nozzle tested. This reduced the time of reading the slides considerably.

   The slides were placed in rows perpendicular to the airstream; the number of slides in each row varied as to the size and shape of the conical spray pattern. The first row was located 2 feet from the nozzle; the second row 5 feet from the nozzle; and the remaining rows at 10-foot intervals for a minimum distance of 50 feet.

TEST RESULTS

Results of some of the atomizers tested are shown in Table I. Initially the selection of the nozzles to be tested was based on the number of nozzles required to give the total system flow rate, their effects on the payload of the airplane, and the horsepower required to overcome the parasite drag of the nozzles and spray boom. After several months of testing, it became apparent that none of the standard type nozzles would meet the preceding requirements and produce a droplet spectrum with maximum size droplets of 50 microns in diameter. For example, the standard hydraulic nozzle in the low flow range will produce small droplets but still not meet the desired 50 micron maximum diameter. For nozzles of this size to meet the total system flow rate would require so many that they would be impractical to install on an airplane. It was then decided to test all

TYPE NOZZLE	SPRAY PRESSURE PSIG	ORIFICE SIZE (INCHES)	FLOW RATE GPM	AIR VELOCITY MPH	ATOMIZER RPM	* NUMBER NOZZLES REQUIRED	LARGEST DROP OBSERVED (MICRONS)	REMARKS
TEEJET FLAT, SPRAY TIP NO. 650017 (SPRAYING SYSTEMS CO.)	400	0.011	.054	150	N-A	H-37 S-148 T-426	120	ORIFICE SO SMALL NOZZLE PLUGS EASILY
TEEJET FLAT, SPRAY TIP NO. 650017 (SPRAYING SYSTEMS CO.)	50	0.011	.019	150	N-A	H-105 S-421 T-1211	160	ORIFICE SO SMALL NOZZLE PLUGS EASILY
TEEJET FLAT SPRAY TIP NO. 6501 (SPRAYING SYSTEMS CO.)	400	0.026	.32	150	N-A	H-7 S-25 T-72	240	
TEEJET FLAT SPRAY TIP NO. 11001 (SPRAYING SYSTEMS CO.)	400	0.026	.32	150	N-A	H-7 S-25 T-72	200	
CONEJET SPRAY TIP NO. TX-1 (SPRAYING SYSTEMS CO.)	400	0.02	.043	150	N-A	H-47 S-186 T-535	240	
TURBAIR ROTARY ELECTRIL ATOMIZER (DISC SPINNER)	40	0.046	.40	85	10900	H-5 S-20 T-58	180	POOR RELIABILITY, HIGH POWER REQUIREMENT AND WEIGHT. EACH UNIT REQUIRES 4.8 AMPS AT 12 V DC AND WEIGHS 6 POUNDS
TURBAIR ROTARY ELECTRIL ATOMIZER (DISC SPINNER)	40	0.041	.30	85	10900	H-7 S-27 T-77	160	
TURBAIR ROTARY ELECTRIL ATOMIZER (DISC SPINNER)	10	0.041	.15	85	10900	H-13 S-53 T-153	140	
TUBE (1/16 INCH OD WITH PLAIN END)	N-A	0.067	.002	150	N-A	H-1000 S-4000 T-11500	140	IMPRACTICAL TO INSTALL THE REQUIRED NUMBER TO GIVE THE DESIRED FLOW RATE ON THE AIRPLANE
TUBE (1/16 INCH OD WITH 45 DEGREE BIAS END)	N-A	0.052	-	150	N-A	NOT DETER-MINED	140	
PNEUMATIC ATOMIZING NOZZLE (SPRAYING SYSTEMS CO. SET UP NO. 29)	5-LIQUID 45-AIR	-	L-.02 A-5.5 SCFM	NONE	N-A	H-100 S-400 T-1150	60	FLOW RATES ARE APPROXIMATE. WEIGHT OF AIR COMPRESSOR REQUIRED TO GIVE THE REQUIRED AIR FLOW WOULD BE SEVERAL TONS

* H- HELICOPTER (BELL) BASED ON FLOW RATE OF 2 GPM
S- SINGLE ENGINE (CESSNA-185) BASED ON FLOW RATE OF 8 GPM
T- TWIN ENGINE (C-47) BASED ON FLOW RATE OF 23 GPM

TABLE I

DROPLET SIZES OBTAINED FROM VARIOUS ATOMIZING DEVICES

sizes of hydraulic nozzles regardless of flow rate to determine if it was at all possible to produce small droplets with a hydraulic nozzle.

Various sizes of the standard hydraulic nozzles such as the Spraying Systems Company flat spray "TeeJet" and "Cone Jet" were tested; the results of only a few tests are shown in Table I. Similar type nozzles from other manufacturers were tested with about the same results (data not reported). In general, the spray tips that produced the smaller drop sizes had such small orifices that plugging of the orifice was a problem.

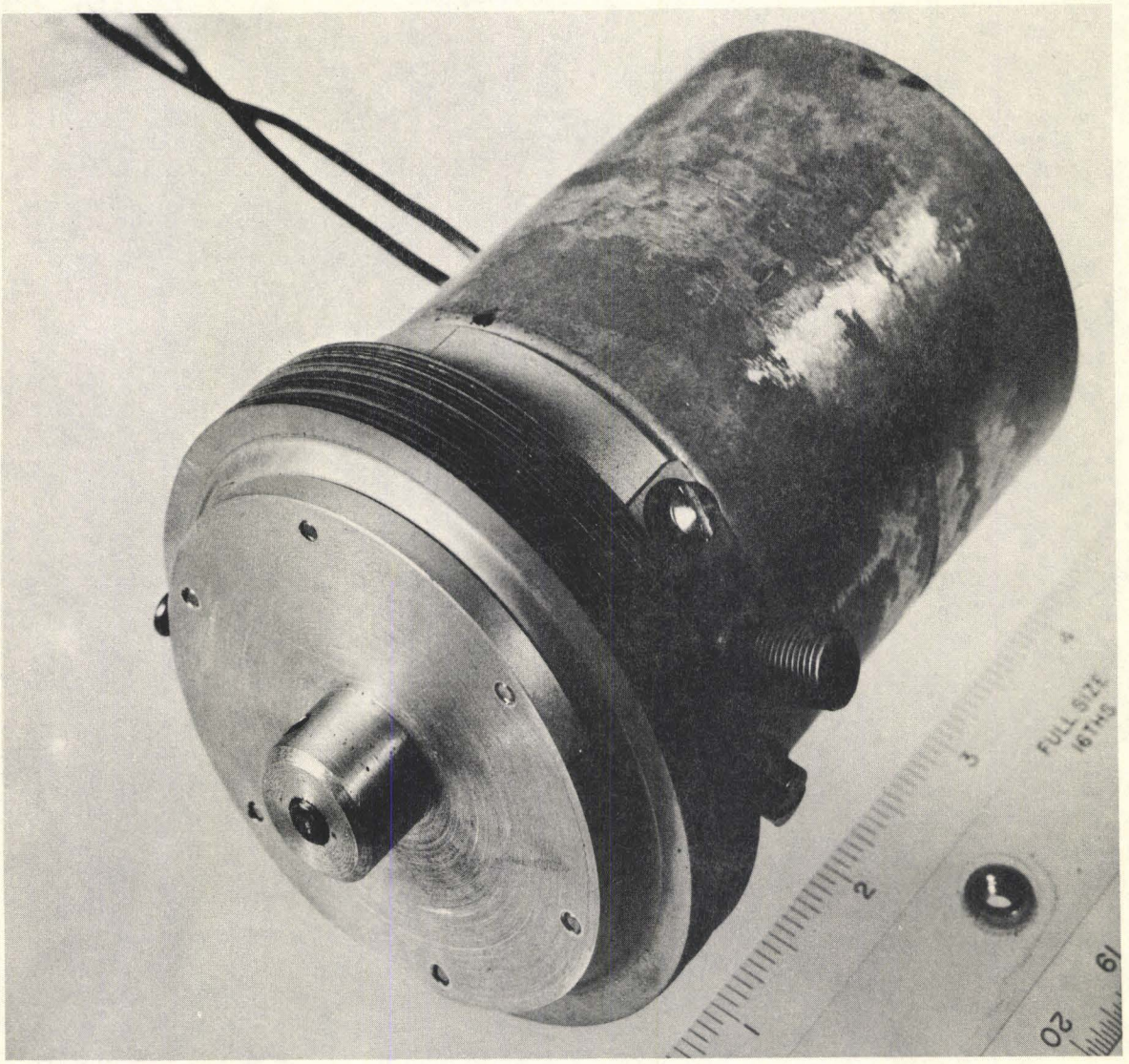
The droplet sizes obtained from an electric motor driven rotary atomizer was encouraging (see Figure 3). This unit was eliminated because so many were required that the drag, weight and electrical power requirements were excessive. Reliability is also a problem with atomizers of this type.

A dozen or more tubes of various sizes and shapes, some of which are shown in Figures 4, 5, 6, and 7, were tested; the results of two of the better ones are shown in Table I. These in general had very small flow rates and would require an enormous number to meet the flow rates desired. Fluid collected on the negative pressure side of some of the tubes forming larger drops that were blown off at random which was very undesirable.

Different types and sizes of pneumatic atomizing nozzles were tested which produced the desired drop size as shown in Table I. Again the liquid flow rate could not be attained with a practical number of nozzles; also the quantity of air required was so exhorbitant that the air delivery system would have been too heavy.

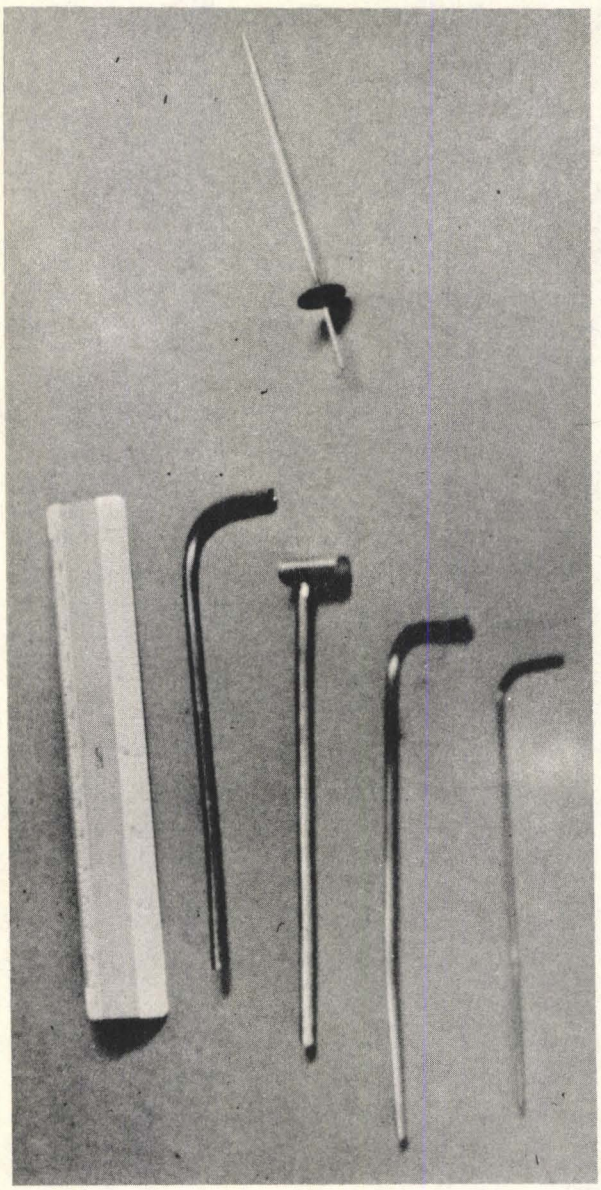
Several atomizers were designed and fabricated by MEDC, such as the porous bronze rotary spinner (Figures 8 and 9) and the rotating valve spinner (Figure 10). These atomizers produced a fine droplet spectrum (results not reported) when all the parts were clean. However, the porous bronze spinner had a tendency to plug up. The rotating valve spinner did not plug up but as foreign material passed between the rotating valve and stationary seat it produced a stream of large drops. These units required very high rotational energy due to bearing and seal friction which was also objectionable, so consequently these concepts were dropped. It was finally concluded that neither hydraulic nozzles, pneumatic atomizing nozzles, nor rotating atomizers would meet the requirements for the spray systems. It was then decided to try a two-phase fluid as an atomizer. Because of its high vapor pressure at normal temperatures, "Freon"[6/] was selected.

6/ FREON - Registered trademark of E. I. duPont and Company for its FLUOROCARBONS.



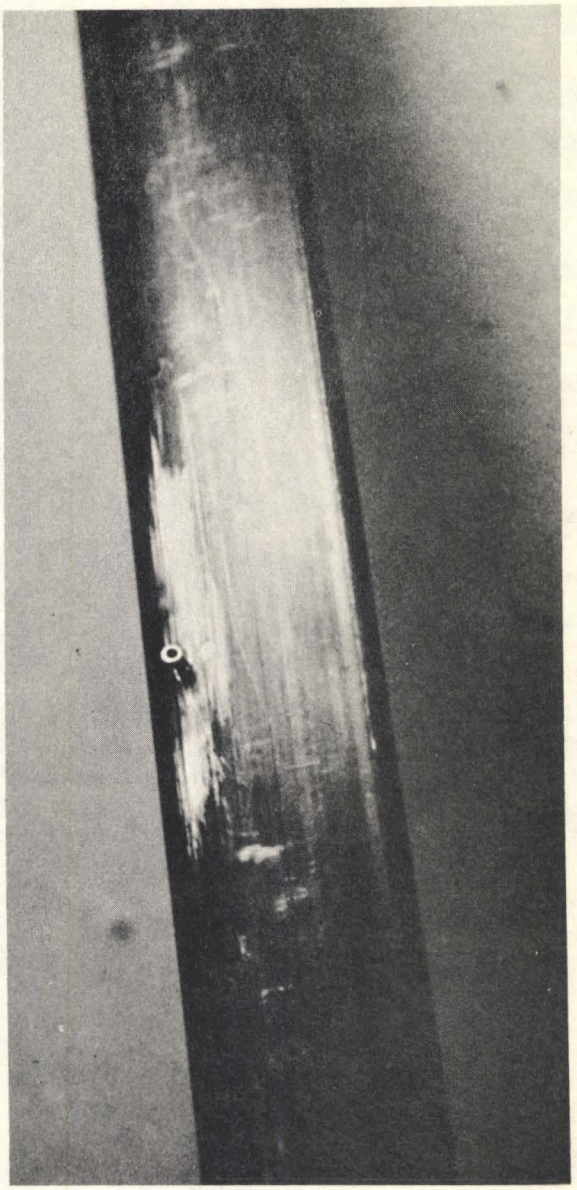
TURBAIR ROTARY ELECTRIC ATOMIZER
(WEIGHT- 6 LBS, DRAWS 5.4 AMPS AT 12 VDC WHEN TURNING 11,000 RPM WITH NO LOAD)

FIGURE 3



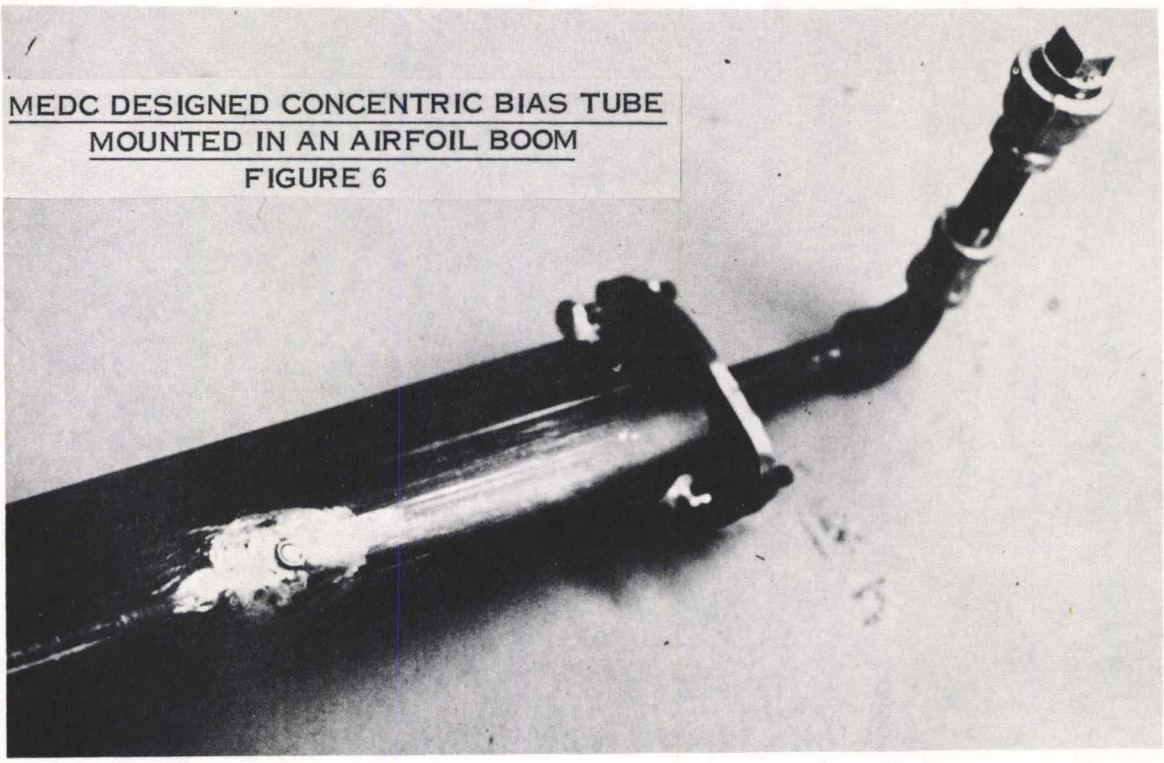
VARIOUS SIZES & SHAPES
OF TUBES TESTED

FIGURE 4

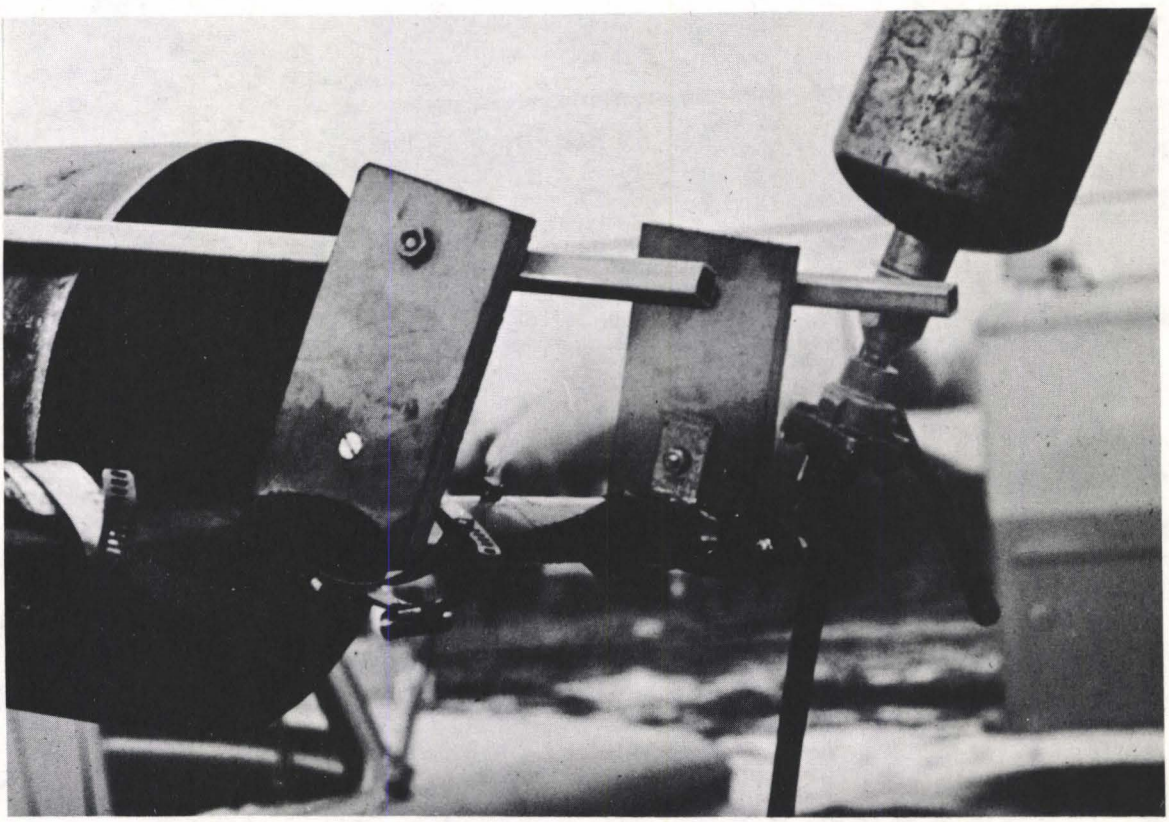


MEDC DESIGNED BIAS TUBE
MOUNTED IN AN AIR FOIL BOOM
(SOME OF THE SPRAY COLLECTED ON THE BOOM)

FIGURE 5

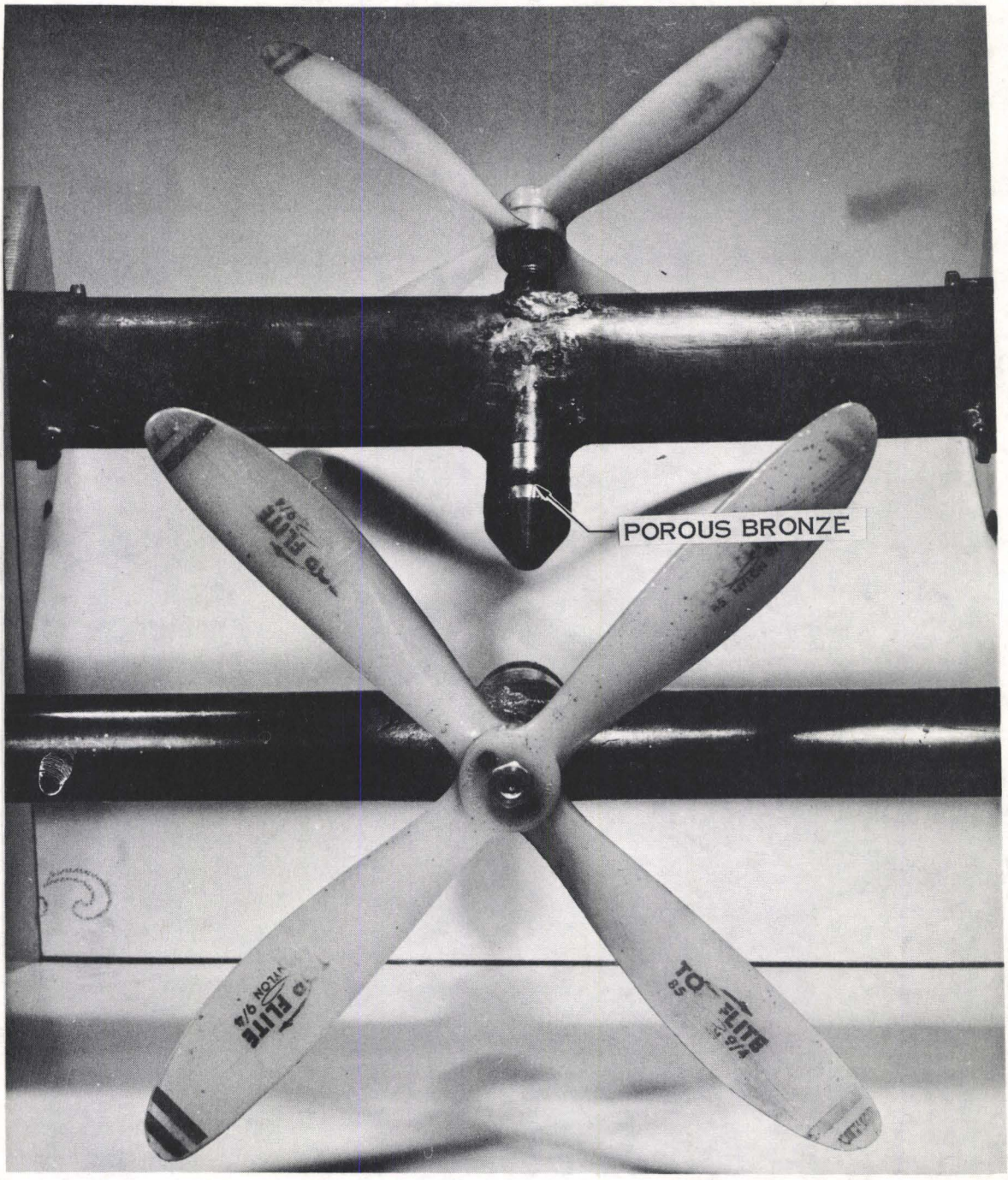


MEDC DESIGNED CONCENTRIC BIAS TUBE
MOUNTED IN AN AIRFOIL BOOM
FIGURE 6



TESTING OF CONCENTRIC BIAS TUBE IN AN 85 MPH AIR STREAM
(SOME OF THE SPRAY COLLECTED ON THE TRAILING EDGE OF THE BOOM)

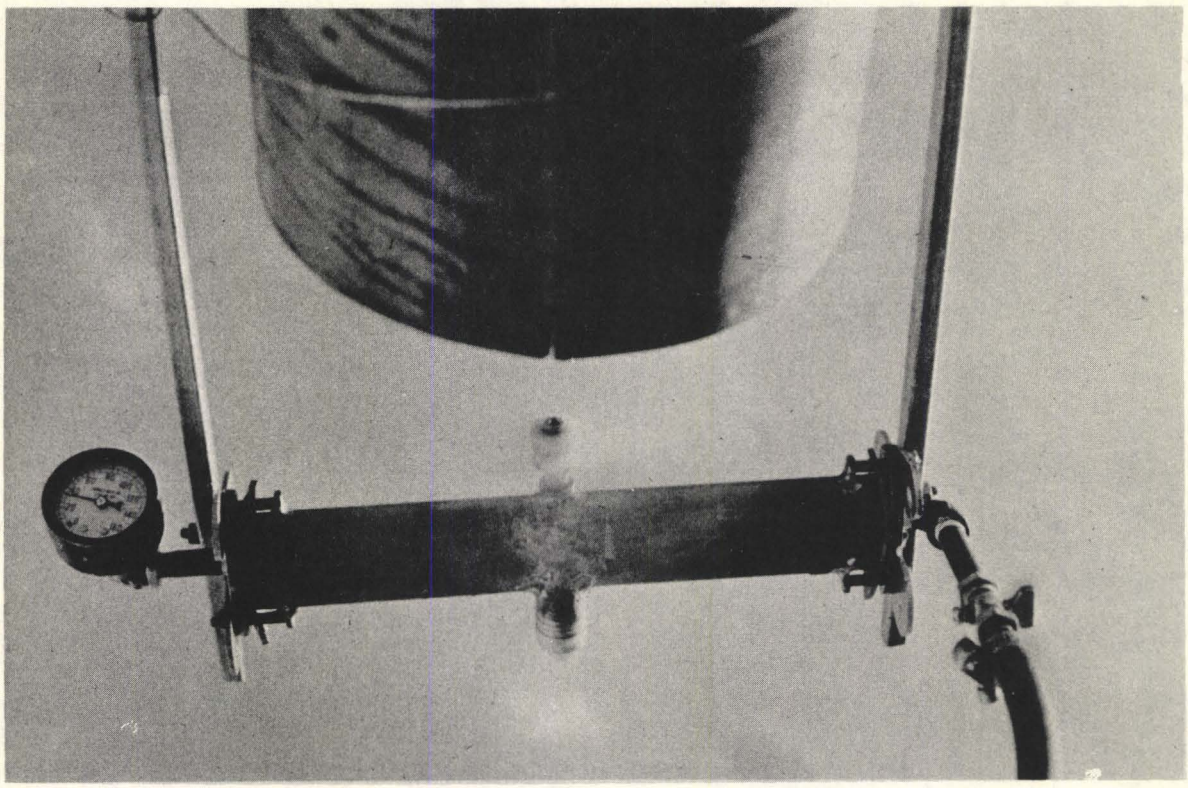
FIGURE 7



MEDC DESIGNED POROUS BRONZE SPINNER

(LIQUID IS SUPPLIED TO THE POROUS BRONZE SLINGER THROUGH THE HOLLOW BOOM, CENTRIFUGAL FORCE AND THE HIGH VELOCITY AIR STREAM SHEAR OFF THE DROPLETS)

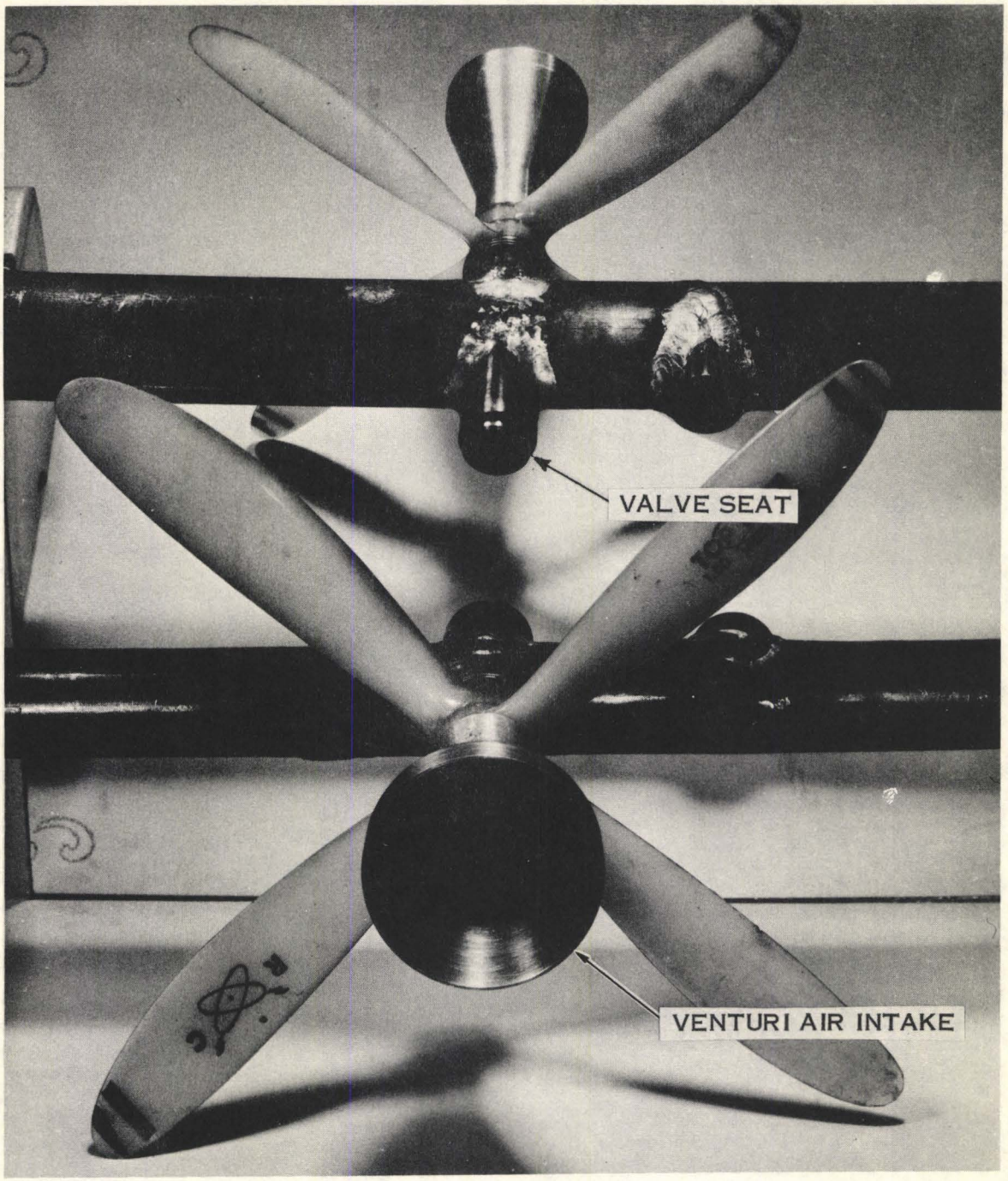
FIGURE 8



TESTING POROUS BRONZE SPINNER IN AN
85 MPH AIR STREAM

(IT REQUIRED HIGH ROTATIONAL ENERGY AND THE POROUS BRONZE SLINGER WOULD PLUG EASILY)

FIGURE 9



MEDC DESIGNED ROTARY VALVE SPINNER

(LIQUID FROM THE BOOM IS FORCED BETWEEN A ROTATING VALVE AND A STATIONARY VALVE SEAT. THE CLEARANCE BETWEEN THE ROTATING VALVE AND ITS SEAT IS ADJUSTABLE TO CONTROL DROPLET SIZE. THE VENTURI RAM AIR INTAKE IN FRONT OF THE SPINNER INCREASES THE AIR VELOCITY OVER THE VALVE AND SEAT PERIPHERY.

FIGURE 10

The bifluid nozzle (Figures 11 and 12) was tested with "Freon" using many combinations of orifice sizes and different size spray tips. Results obtained from a few lab tests are shown in Table II. Also shown are droplet sizes obtained from actual field tests using the C-47 airplane equipped with bifluid nozzles. These field tests used the same airplane bifluid nozzle configuration and operating conditions as were used on the 1967 pilot tests except for the number of nozzles. The largest droplets observed from the field tests were 120 microns in diameter.

Table III shows the results obtained in actual field tests with the C-47 airplane equipped with the Spraying Systems Company TX-26 spray tip (Figure 13) spraying a solution containing 50% by weight of atomizing fluid and insecticide carrier. The nozzle spacing was varied to determine if it would affect droplet size. The results indicated no significant change in droplet size with an average maximum droplet diameter of 120 microns for the six runs. The C-47 airplane solution spray system used on the 1968-69 pilot tests used the same nozzles and solution with a 3" nozzle spacing and more nozzles.

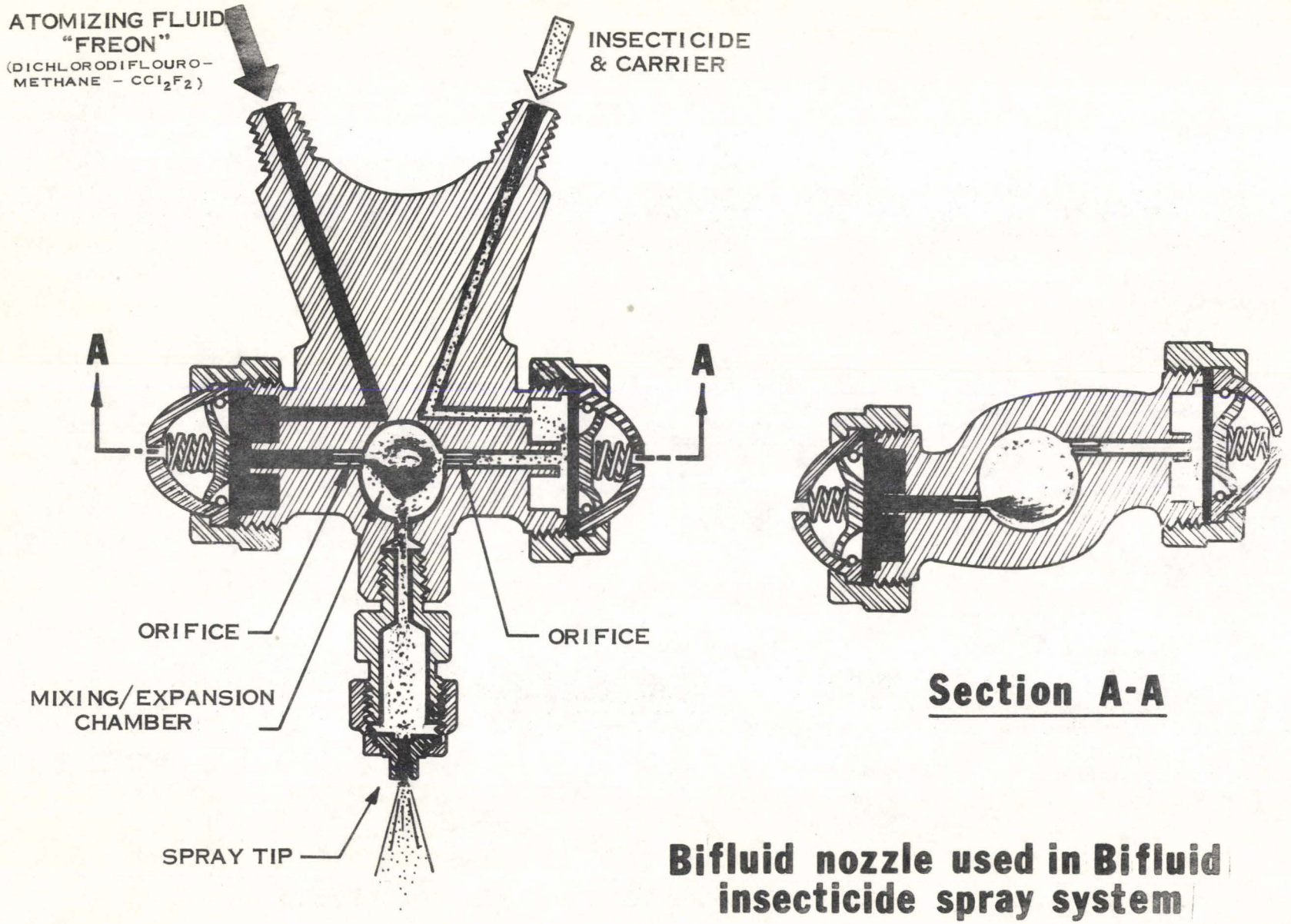
BIFLUID NOZZLE

After considerable testing of standard spray type hardware and systems it became apparent that this type equipment would not meet the drop size requirements. Some of the equipment produced a fine droplet spectrum but in every case other limitations as discussed in the test results made the equipment impractical to use on an airplane. It was then decided to try an atomizing fluid in solution with the insecticide carrier as is used in common household aerosol dispensers.

A solution of the insecticide carrier (Dowanol-TPM) and the atomizing fluid (Freon-12) was tested. The initial tests were made with a mixture of equal volumes of the carrier and atomizing fluid in a pressurized container and spraying through a flat fan spray tip. The results of the tests did not show a significant reduction in droplet size so it was concluded that the carrier and atomizing fluid were immiscible. It was then decided to try to produce a mechanical mixture of the carrier and atomizing fluid by use of the bifluid nozzle (Figure 11). (Later, when it was found that the fluids were miscible, it became apparent that the reason these tests with a solution of the two fluids failed was because the spray nozzles used did not have an expansion chamber before the exit orifice.)

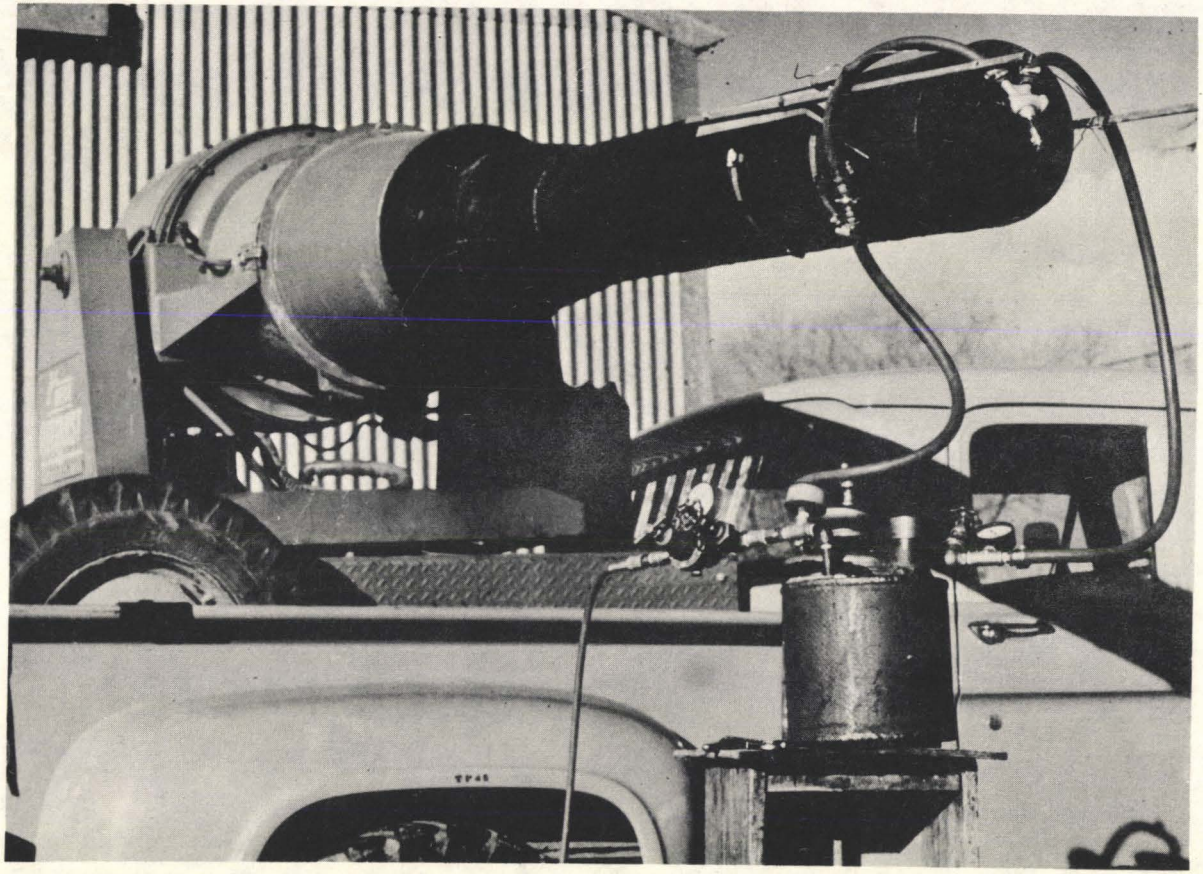
The bifluid nozzle, equipped with two equal diameter orifices and flat fan type spray tips, produced a comparatively small drop size spectrum and from visual observations produced a tremendous number of fines. These results were encouraging because of the drop size and also because the spray system appeared feasible with fewer limitations.

The disadvantages of this approach were the cost of the atomizing fluid and the decrease in the quantity of insecticide carrier because of the space and



Bifluid nozzle used in Bifluid insecticide spray system

FIGURE II



SET UP USED TO TEST BIFLUID NOZZLE

FIGURE 12

TYPE ATOMIZER	ATOMIZING FLUID: ORIFICE SIZE (WIRE GAUGE)	ATOMIZING FLUID: TANK PRESSURE (PSIG)	INSECTICIDE & CARRIER: ORIFICE SIZE (WIRE GUAGE)	INSECTICIDE & CARRIER: TANK PRESSURE (PSIG)	VAPOR PRESSURE (PSIG) (ATOMIZING FLUID)	MIXING & EXPANSION CHAMBER PRESSURE (PSIG)	RATIO ATOMIZING FLUID TO INSECTICIDE & CARRIER (WT/WT)	FLOW RATE (GPM) (INSECTICIDE & CARRIER)	INDICATED AIR SPEED (MPH)	NUMBER NOZZLES REQUIRED FOR C-47 BASED ON C-47 FLOW RATE OF 23 GPM	LARGEST DROP OBSERVED (MICRONS)	REMARKS
BIFLUID NOZZLE WITH 8004 SPRAY TIP	NO. 70	85	NO. 70	85	70	46	1-1	.126	85	183	120	RESULTS OBTAINED FROM LAB TEST.
	NO. 70	85	NO. 60	85	70	47	1-2	.25	85	92	160	
	NO. 70	85	NO. 54	85	55	55	1-3.5	.383	85	60	200	
RUN 1	NO. 70	85	NO. 70	85	69	46	1-1	.126	150	183	100	RESULTS OBTAINED FROM ACTUAL FIELD TESTS WITH C-47 AIRPLANE EQUIPPED WITH 33 BIFLUID NOZZLES (FLOW RATE, RATIOS, & VAPOR PRESSURES WERE DETERMINED IN LAB TESTS). THIS CONFIGURATION WAS USED IN THE 1967 SPRAY PROJECT.
RUN 2	NO. 70	85	NO. 70	85	69	46	1-1	.126	150	183	110	
RUN 3	NO. 70	85	NO. 70	85	69	46	1-1	.126	150	183	160	
RUN 4	NO. 70	85	NO. 70	85	67	46	1-1	.126	150	183	130	
RUN 5	NO. 70	85	NO. 70	85	67	46	1-1	.126	150	183	120	

BIFLUID NOZZLE - (STULL CHEMICAL COMPANY)
8004 SPRAY TIP - (SPRAYING SYSTEMS COMPANY)

TABLE II
BIFLUID SYSTEM

RUN	SPRAY PRESSURE (PSIG)	SOLUTION VAPOR PRESSURE (PSIG)	INSECTICIDE CARRIER FLOW RATE GPM PER NOZZLE	ATOMIZING FLUID FLOW RATE GPM PER NOZZLE	TOTAL FLOW RATE - GPM PER NOZZLE ATOMIZING FLUID & INSECTICIDE CARRIER	RATIO ATOMIZING FLUID TO INSECTICIDE CARRIER (WT WT)	NUMBER OF NOZZLES	NOZZLE SPACING (INCHES)	INDICATED AIRSPEED (MPH)	ABSOLUTE ALTITUDE IN FEET	LARGEST DROP OBSERVED (MICRONS)
1	60	58	0.21	0.15	0.36	1—1	68	5	150	50	120
2	60	58	0.21	0.15	0.36	1—1	68	5	150	50	130
3	60	58	0.21	0.15	0.36	1—1	68	5	150	50	140
4	60	55	0.21	0.15	0.36	1—1	86	2.5	150	50	130
5	60	55	0.21	0.15	0.36	1—1	86	2.5	150	50	110
6	60	55	0.21	0.15	0.36	1—1	86	2.5	150	50	100

RESULTS OBTAINED FROM FIELD TEST USING C-47 AIRPLANE

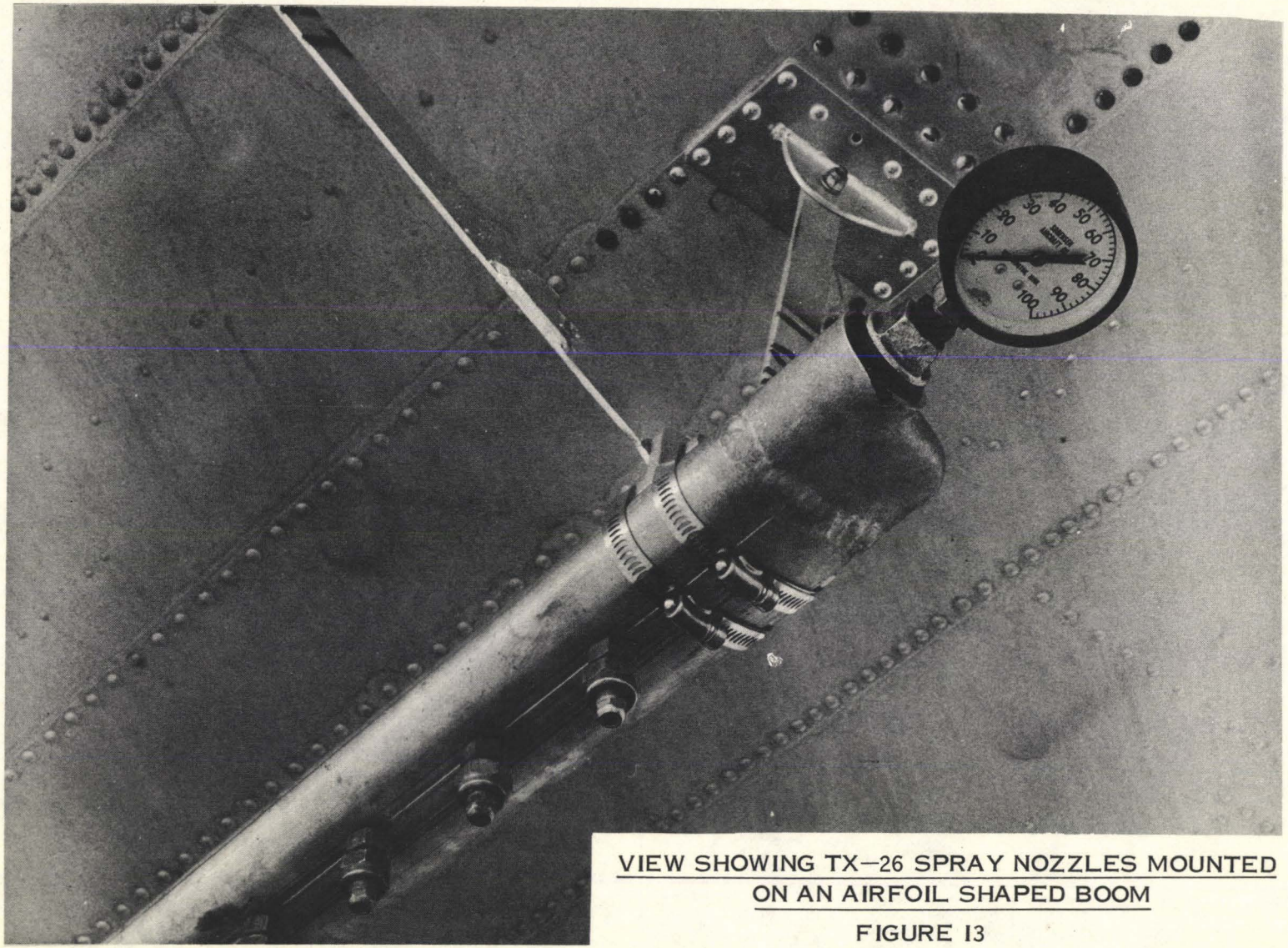
FLOW RATES WERE DETERMINED IN LAB TESTS

IT WOULD REQUIRE 214 NOZZLES TO OBTAIN THE DESIRED C-47 AIRPLANE FLOW RATE OF 45 GPM OF INSECTICIDE CARRIER.

TABLE III

SOLUTION SYSTEM

(SPRAYING A SOLUTION 50 PERCENT BY WEIGHT OF FREON-12 AND DOWANOL TPM)



VIEW SHOWING TX—26 SPRAY NOZZLES MOUNTED ON AN AIRFOIL SHAPED BOOM

FIGURE 13

weight needed for the atomizing fluid. To keep these disadvantages at a minimum it was decided that a weight ratio of atomizing fluid to carrier greater than one would not be acceptable if the system was to be practical. (The common household aerosol dispenser contains 85% of atomizing fluid by weight.) It was thought that the amount of atomizing fluid could be substantially reduced by utilizing it more efficiently through better combinations of orifices and spray tips.

Many sizes and combinations of metering orifices and spray tips were tested to determine what configuration would produce the smallest drop spectrum. By varying the metering orifices, the volume ratios of the atomizing fluid and the carrier fluid were changed. By varying the spray tip sizes the pressure drop in the mixing chamber would change. Because of these several variables a systematic method of testing had to be performed in which only one variable was changed at one time to narrow the test data within meaningful limits.

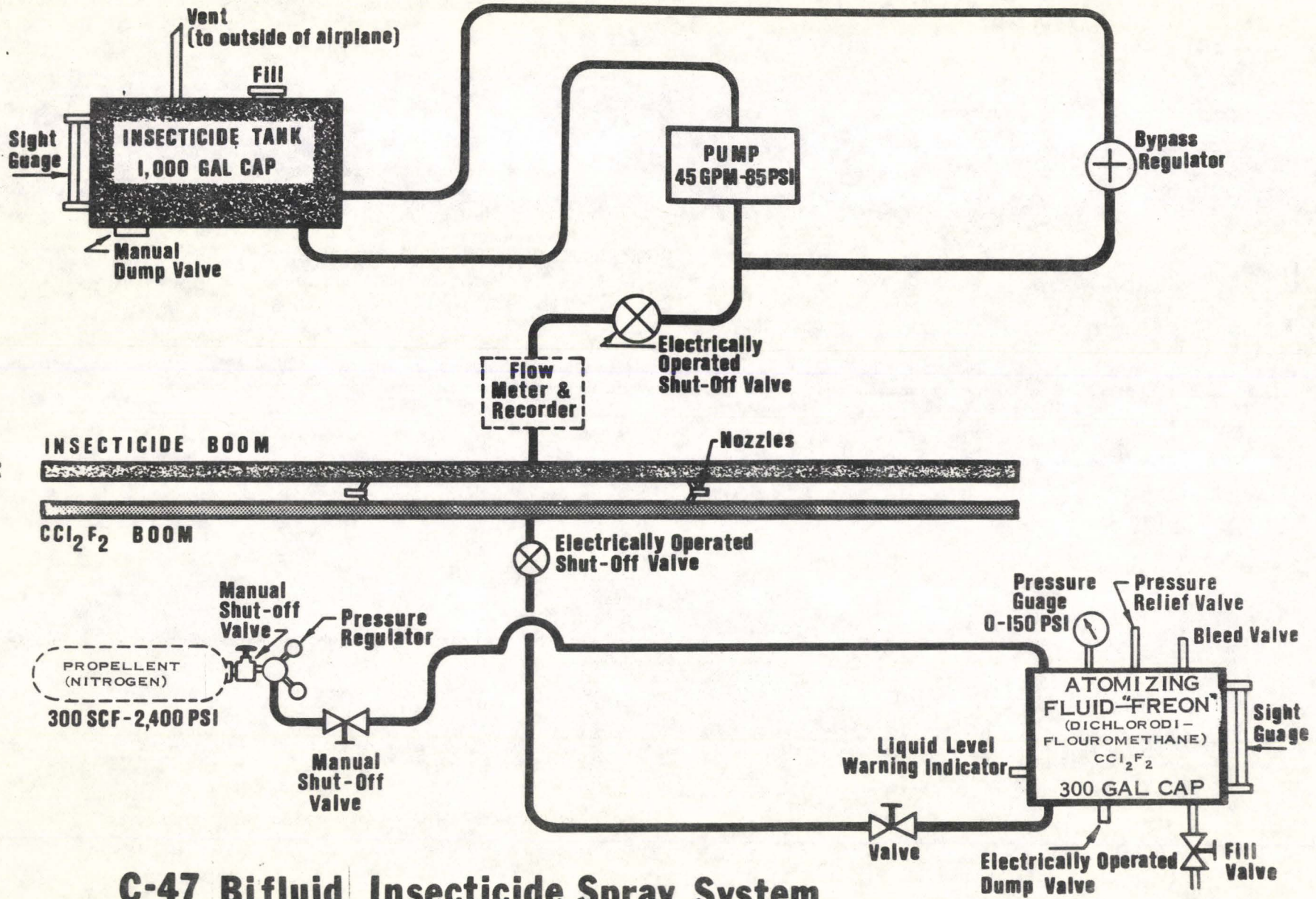
The pressure drop into the mixing chamber was varied from 0 to 25 psig to determine the vapor pressure drop needed to produce the most efficient atomization. It was found that a pressure drop of 20 to 25 psig below the vapor pressure of the atomizing fluid was required to produce the smallest drop spectrum. This is attributed to the fact that the atomizing fluid must flash into a vapor to acquire a high velocity before exiting from the spray tip. The high exit velocity and continued rapid expansion of the atomizing fluid is the mechanics of generating small droplets.

In an attempt to reduce the quantity of atomizing fluid needed, tests were made on varying quantities of the two fluids metered into the mixing chamber of the bifluid nozzle while still maintaining the desired pressure drops. The weight ratio of the atomizing fluid to the carrier fluid was varied in small increments from 1:1 to 1:3. The best results were obtained with the 1:1 ratio with the bifluid nozzle equipped with number 70 (0.028 inch in diameter) metering orifices and the Spray Systems Company number 8004 spray tip. It produced a drop spectrum with 120 microns as the largest diameter drops.

BIFLUID SPRAY SYSTEM

From results of preliminary tests on the bifluid nozzle in early February 1967, the decision was made to equip the three aircraft (Douglas C-47, Cessna 185, and Bell Helicopter 47G3B1) for the 1967 spray project with a bifluid spray system. The bifluid nozzle had produced a small droplet spectrum, was feasible to use on aircraft and thus was the most practical of all the systems tested.

With only four months left to equip the three aircraft, it was decided to acquire a conventional spray system and add to it the atomizing fluid system. This was possible because in essence the two fluid systems were separate until the fluids merged at the nozzle. Figure 14 is a schematic



C-47 Bifluid Insecticide Spray System

FIGURE 14

of the bifluid system for the C-47 airplane; the systems for the other two aircraft were the same except for the size of the equipment. From Figure 14 it can be seen that everything above and including the insecticide boom is a conventional spray system and everything below the insecticide boom is the atomizing fluid system. Therefore, the bifluid system was essentially two systems, a conventional spray system and an atomizing fluid system, that merged at the nozzles.

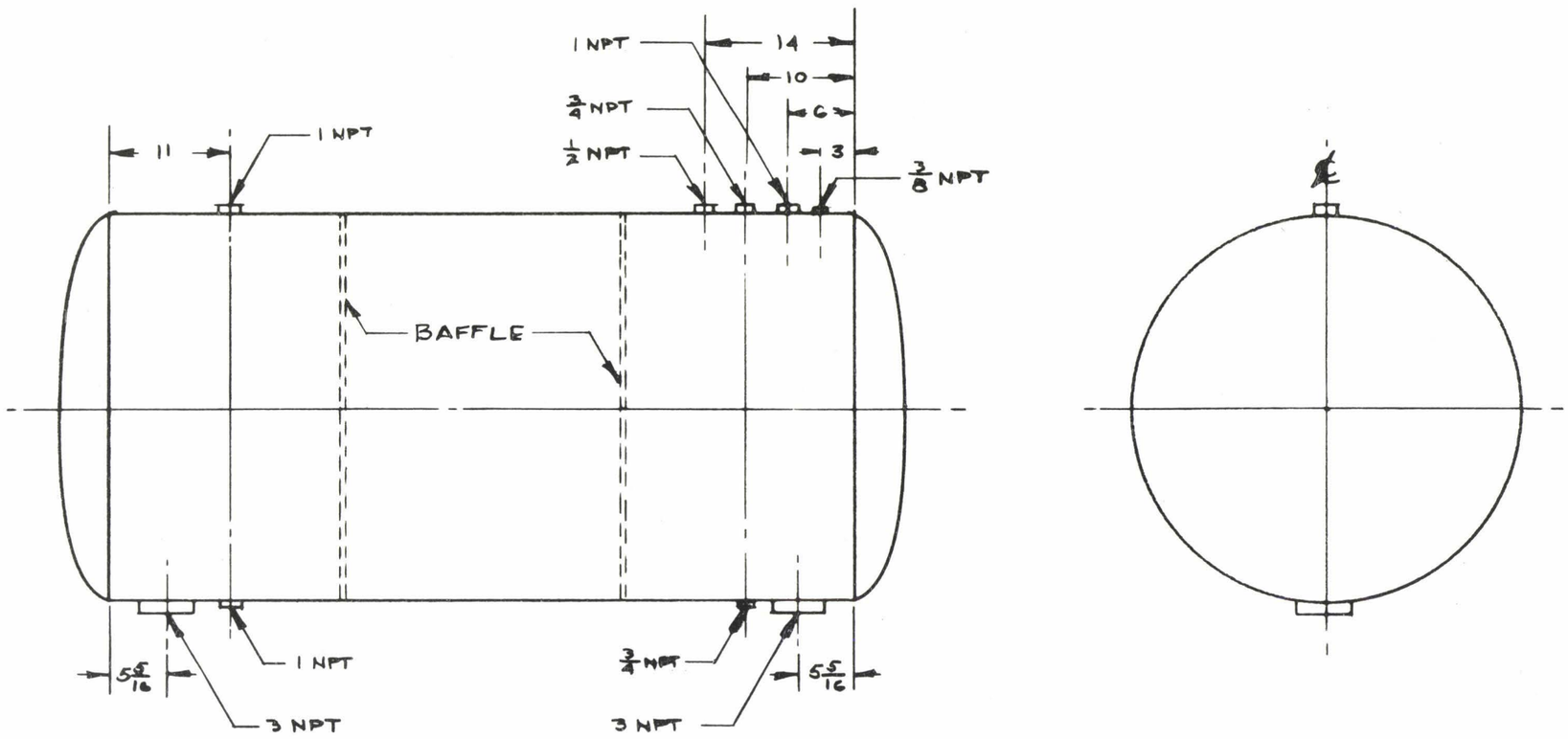
The design capacities of the three aircraft are shown in Table IV. Based on these capacities and schematic of the system (Figure 14) commercial firms were contacted and asked for an estimate on the design, fabrication and installation of a bifluid system for the three aircraft. The only company interested gave an estimate of approximately $47,000 and stipulated that they needed the three aircraft at their plant for three months. Because of the cost and time involved this approach was dropped.

It was then decided that MEDC would purchase a conventional spray system for each of the aircraft, design and purchase all components for the atomizing fluid system and contract the installation only. The aircraft manufacturer of the Cessna airplane and Bell helicopter gave recommendations as to where to obtain an approved spray system for their aircraft. Based on these recommendations, conventional spray systems for the Cessna airplane and Bell helicopter were purchased from Sorensen Aircraft Company, Worthington, Minnesota, and Simplex Manufacturing Company, Portland, Oregon, respectively. A commercial manufacturer of a spray system for the C-47 could not be found. However, one aerial applicator, Hillcrest Aircraft Company, indicated that they had experience in fabricating a C-47 spray system and would be interested in building one for us. They were given the contract to fabricate the conventional spray system for the C-47 and the installation of the atomizing fluid system and joining the two together.

The atomizing fluid (dichlorodifluoromethane) has a vapor pressure of approximately 70 psig at $70^{\circ}F$; therefore, the tanks had to be pressure vessels. Specifications for these atomizing fluid tanks (Figures 15, 16 and 17) were drawn up and the contract for fabrication awarded to Hulbert Brothers, Salt Lake City, Utah, with a specified delivery date of June 1, 1967. Due to an error in fabrication of the tank heads by a subcontractor, the contract had to be extended for 30 days with instructions to complete the 45 gallon tank for the Cessna first. This delay in delivery of the tank consequently delayed the delivery of the aircraft to the spray project.

The installation of the bifluid spray system on the Cessna 185 was completed on June 16, 1967, by Johnson Flying Service, Missoula, Montana. However, because of an engine failure, the atomizing fluid portion of the bifluid system was removed and installed on a Grumman TBM to complete the project.

The bifluid spray system was installed on a helicopter (Figures 18, 19, 20 and 21) by Intermountain Flying Service, Provo, Utah. The helicopter was ready for use on June 22, 1967, and according to the pilot, performed well. For capacities of the helicopter bifluid spray system see Table IV.



SPECIFICATIONS

1. TANK SHALL CONFORM TO ASME UNFIRED PRESSURE VESSEL CODE AND BE LABELED.
2. TANK MATERIAL SHALL BE ALUMINUM ALLOY.
3. TANK SHALL HAVE TORISPHERICAL HEADS 36 INCHES IN DIAMETER.
4. TANK SHALL HAVE A WORKING PRESSURE OF 100 PSI AT 100° F.
5. ALL OUTLETS SHALL BE WELDED FLANGE TYPE WITH FEMALE NPT AS SHOWN.
6. 2 BAFFLES SHALL BE PLACED INSIDE THE TANK SO AS TO DIVIDE THE TANK INTO 3 EQUAL VOLUMES.
7. TANK SHALL HAVE A CAPACITY OF APPROXIMATELY 320 U. S. LIQUID GALLONS.
8. OVERALL LENGTH OF TANK SHALL NOT EXCEED 6 FT 8 IN.

DATE	REVISION	BY

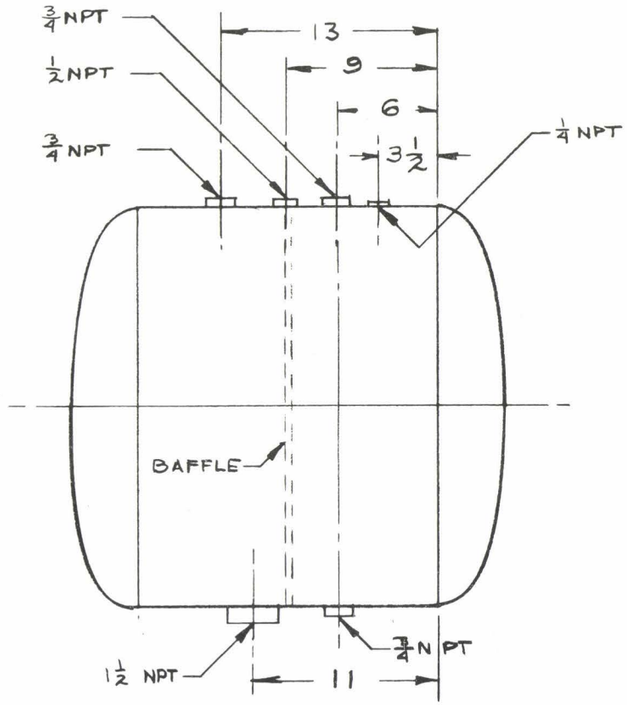
U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
EQUIPMENT DEVELOPMENT CENTER
MISSOULA, MONTANA

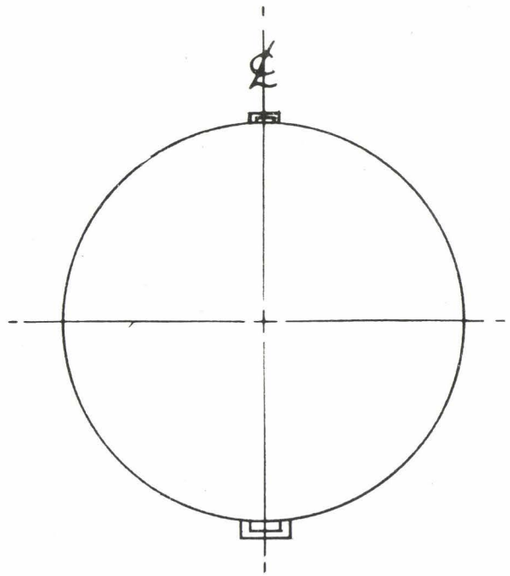
TITLE

AIRCRAFT SPRAY TANK 320 GAL

DRAWN BY LASSILA	TOLERANCES
DESIGNED TJ	FRACTIONS ±
CHECKED Aey	DECIMALS ±
APPROVED	ANGLES ±
SCALE NONE	
DATE APRIL 1967	DRAWING NUMBER
SHEET 1 OF 1	MEDC-350

FIGURE 15





SPECIFICATIONS

1. TANK SHALL CONFORM TO ASME UNFIRED PRESSURE VESSEL CODE AND BE LABELED.
2. TANK MATERIAL SHALL BE ALUMINUM ALLOY.
3. TANK SHALL HAVE TORISPHERICAL HEADS 24 INCHES IN DIAMETER.
4. TANK SHALL HAVE A WORKING PRESSURE OF 100 PSI AT 100° F.
5. ALL OUTLETS SHALL BE WELDED FLANGE TYPE WITH FEMALE NPT AS SHOWN.
6. ONE BAFFLE SHALL BE PLACED INSIDE THE TANK SO AS TO DIVIDE THE TANK INTO 2 EQUAL VOULUMES.
7. TANK SHALL HAVE A CAPACITY OF APPROXIMATELY 45 U. S. LIQUID GALLONS.
8. OVERALL LENGTH OF TANK SHALL NOT EXCEED 27 INCHES.

DATE	REVISION	BY

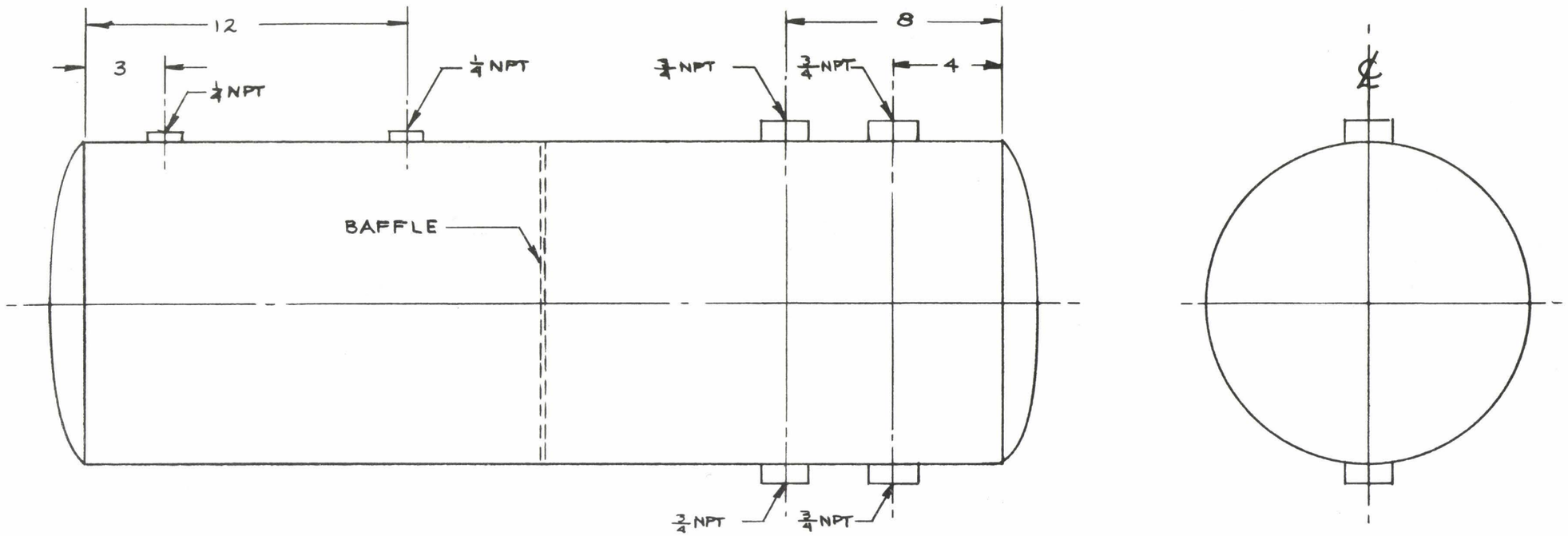
U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
EQUIPMENT DEVELOPMENT CENTER
MISSOULA, MONTANA

TITLE

AIRCRAFT SPRAY TANK 45 GAL

DRAWN BY LASSILA	TOLERANCES UNLESS OTHERWISE STATED
DESIGNED TJ	FRACTIONS ±
CHECKED Aej	DECIMALS ±
APPROVED	ANGLES ±
SCALE NONE	DRAWING NUMBER
DATE APRIL 1967	MEDC-349
SHEET 1 OF 1	

FIGURE 16



SPECIFICATIONS

1. TANK SHALL CONFORM TO ASME UNFIRED PRESSURE VESSEL CODE AND BE LABELED.
2. TANK MATERIAL SHALL BE ALUMINUM ALLOY.
3. TANK SHALL HAVE TORISPHERICAL HEADS 12 INCHES IN DIAMETER.
4. TANK SHALL HAVE A WORKING PRESSURE OF 100 PSI AT 100° F.
5. ALL OUTLETS SHALL BE WELDED FLANGE TYPE WITH FEMALE NPT AS SHOWN.
6. ONE BAFFLE SHALL BE PLACED INSIDE SO AS TO DIVIDE THE TANK INTO 2 EQUAL VOLUMES.
7. TANK SHALL HAVE A CAPACITY OF 17 1/2 ± 1/2 U. S. LIQUID GALLONS.

DATE	REVISION	BY

U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
EQUIPMENT DEVELOPMENT CENTER
MISSOULA, MONTANA

TITLE

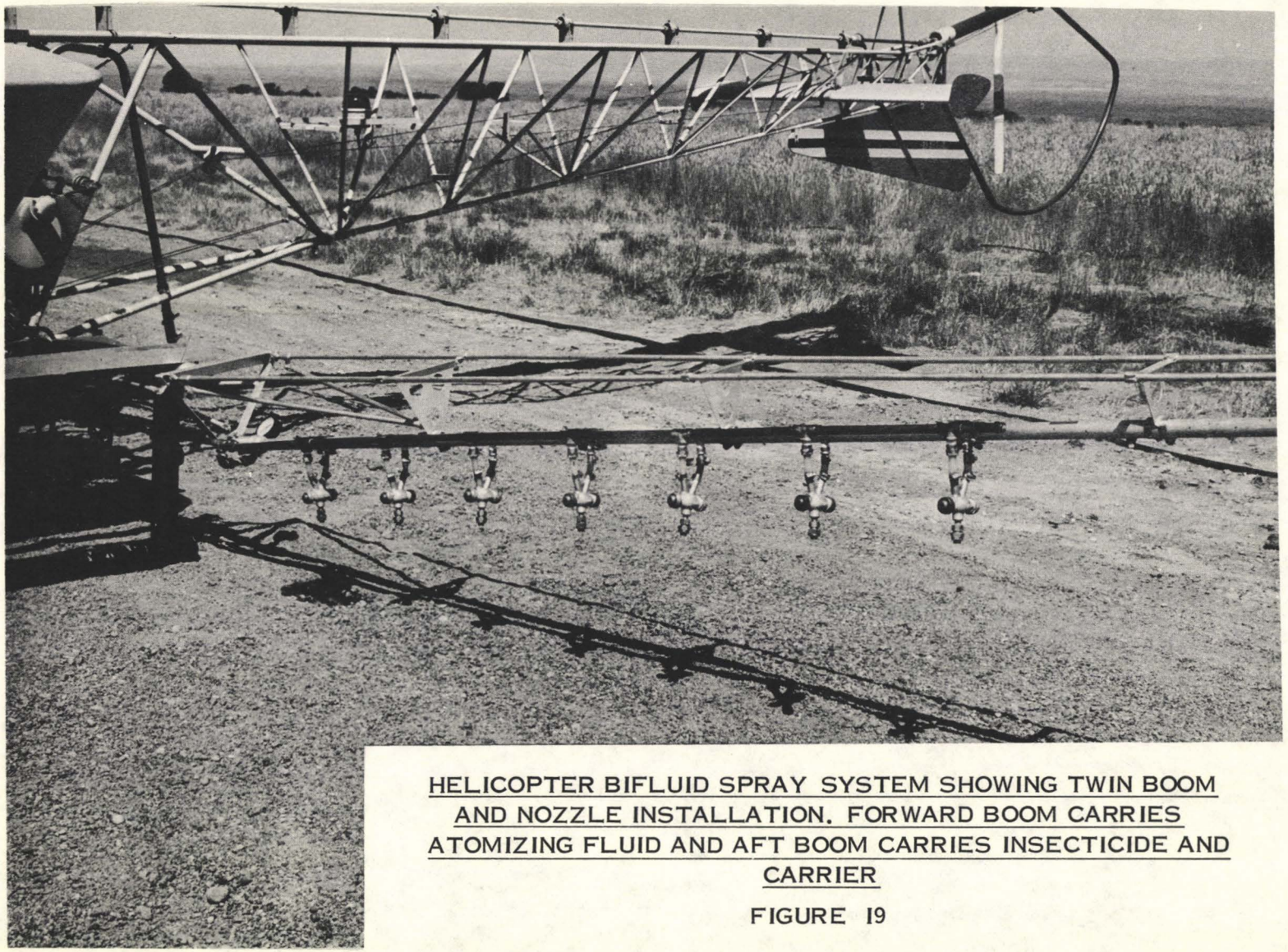
AIRCRAFT SPRAY TANK 17½ GAL

DRAWN BY LASSILA	TOLERANCES (UNLESS OTHERWISE NOTED)
DESIGNED TJ	FRACTIONS ±
CHECKED	DECIMALS ±
APPROVED	ANGLES ±
SCALE NONE	
DATE APRIL 1967	DRAWING NUMBER
SHEET 1 OF 1	MEDC-348

FIGURE 17

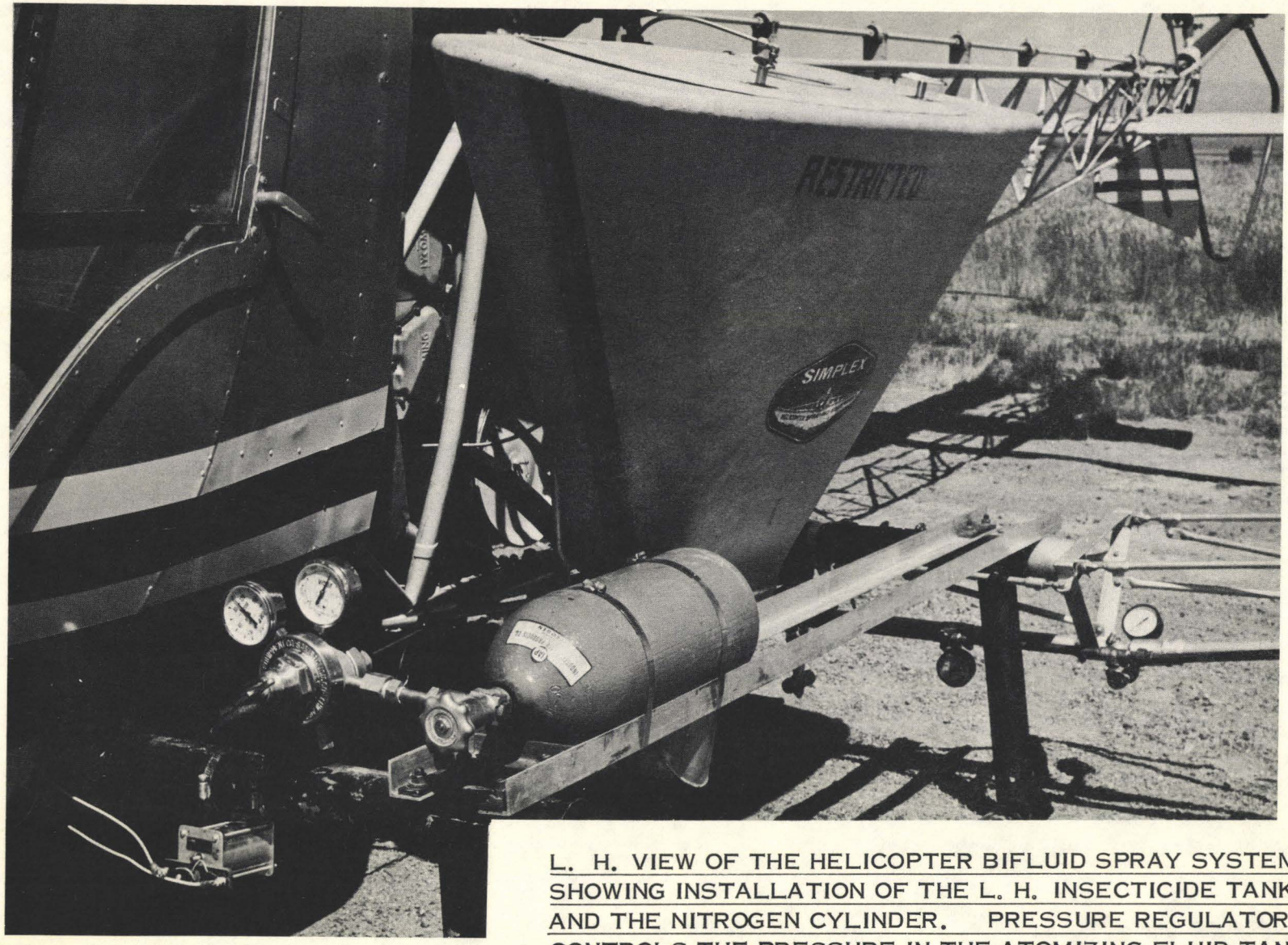
BELL MODEL 47G—3B—1 HELICOPTER EQUIPPED
WITH THE BIFLUID SPRAY SYSTEM

FIGURE 18



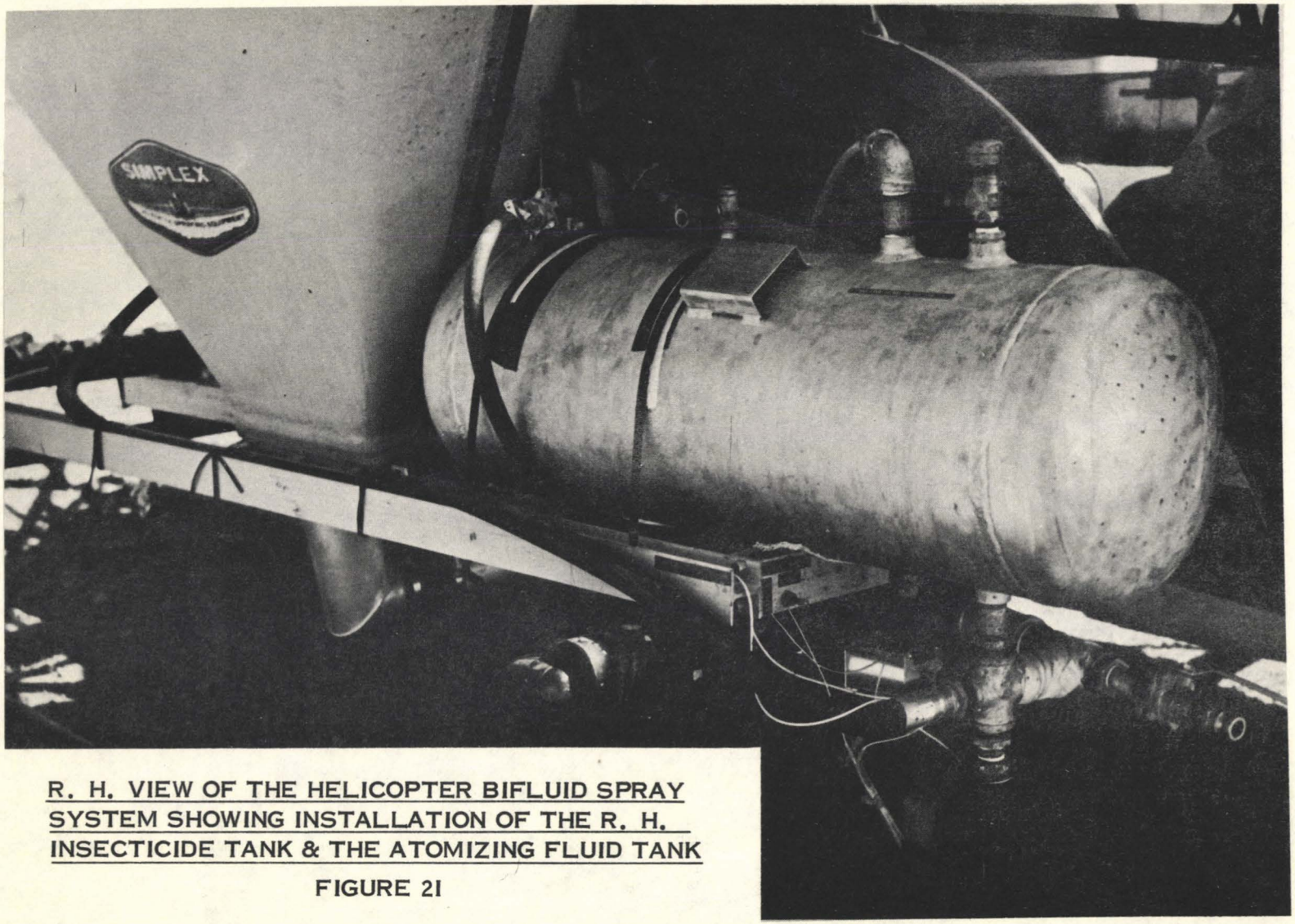
HELICOPTER BIFLUID SPRAY SYSTEM SHOWING TWIN BOOM AND NOZZLE INSTALLATION. FORWARD BOOM CARRIES ATOMIZING FLUID AND AFT BOOM CARRIES INSECTICIDE AND CARRIER

FIGURE 19



L. H. VIEW OF THE HELICOPTER BIFLUID SPRAY SYSTEM SHOWING INSTALLATION OF THE L. H. INSECTICIDE TANK AND THE NITROGEN CYLINDER. PRESSURE REGULATOR CONTROLS THE PRESSURE IN THE ATOMIZING FLUID TANK.

FIGURE 20



R. H. VIEW OF THE HELICOPTER BIFLUID SPRAY SYSTEM SHOWING INSTALLATION OF THE R. H. INSECTICIDE TANK & THE ATOMIZING FLUID TANK

FIGURE 21

	DESIGN CAPACITY			ACTUAL CAPACITY①		
	DOUGLAS C-47	CESSNA② 185	BELL 47G3B1 COPTER	DOUGLAS C-47	GRUMMAN② TBM	BELL 47G3B1 COPTER
TANK SIZES- INSECTICIDE TANK (GAL)	1000	160	90	1000	UNKNOWN	90
ATOMIZING FLUID TANK (GAL)	320	45	17.5	320	45	17.5
NUMBER OF BIFLUID NOZZLES	150	50	20	94	48	14
FLOW RATE-INSECTICIDE & CARRIER (GAL)	23	8	2.5	12	5.6	1.8
RATIO-ATOMIZING FLUID TO INSECTICIDE	1 TO 3	1 TO 3	1 TO 1	1 TO 1	1 TO 1	1 TO 1
SPRAY PRESSURE- INSECTICIDE (PSIG)	85	85	85	85	85	85
ATOMIZING FLUID (PSIG)	85	85	85	85	85	85

NOTES-

① WITH AN ACTUAL RATIO OF ATOMIZING FLUID TO INSECTICIDE & CARRIER OF 1 TO 1, APPROXIMATELY EQUAL VOLUMES WERE PLACED IN THE INSECTICIDE AND ATOMIZING FLUID TANKS. THE FULL CAPACITY OF THE INSECTICIDE TANK WOULD BE UTILIZED ONLY WHEN SPRAYING AS A CONVENTIONAL SPRAY SYSTEM WITH THE ATOMIZING FLUID SYSTEM REMOVED.

② DUE TO ENGINE FAILURE, THE ATOMIZING FLUID PORTION OF THE CESSNA 185 BIFLUID SPRAY SYSTEM WAS TRANSFERRED TO A GRUMMAN TBM AND THE CESSNA WAS NOT USED.

TABLE IV

AIRCRAFT BIFLUID SPRAY SYSTEM CAPACITY

Due to late delivery of materials the installation of the bifluid spray system on the C-47 (Figures 22, 23, 24, 25, 26, 27, 28, 29, and 30) was not completed until July 13, 1967. During flight tests it was determined that the spray capacity, shown in Table IV, of 150 nozzles would have to be reduced to 94 nozzles due to excessive drag. The C-47 bifluid spray system was then ready for use.

SOLUTION SYSTEM

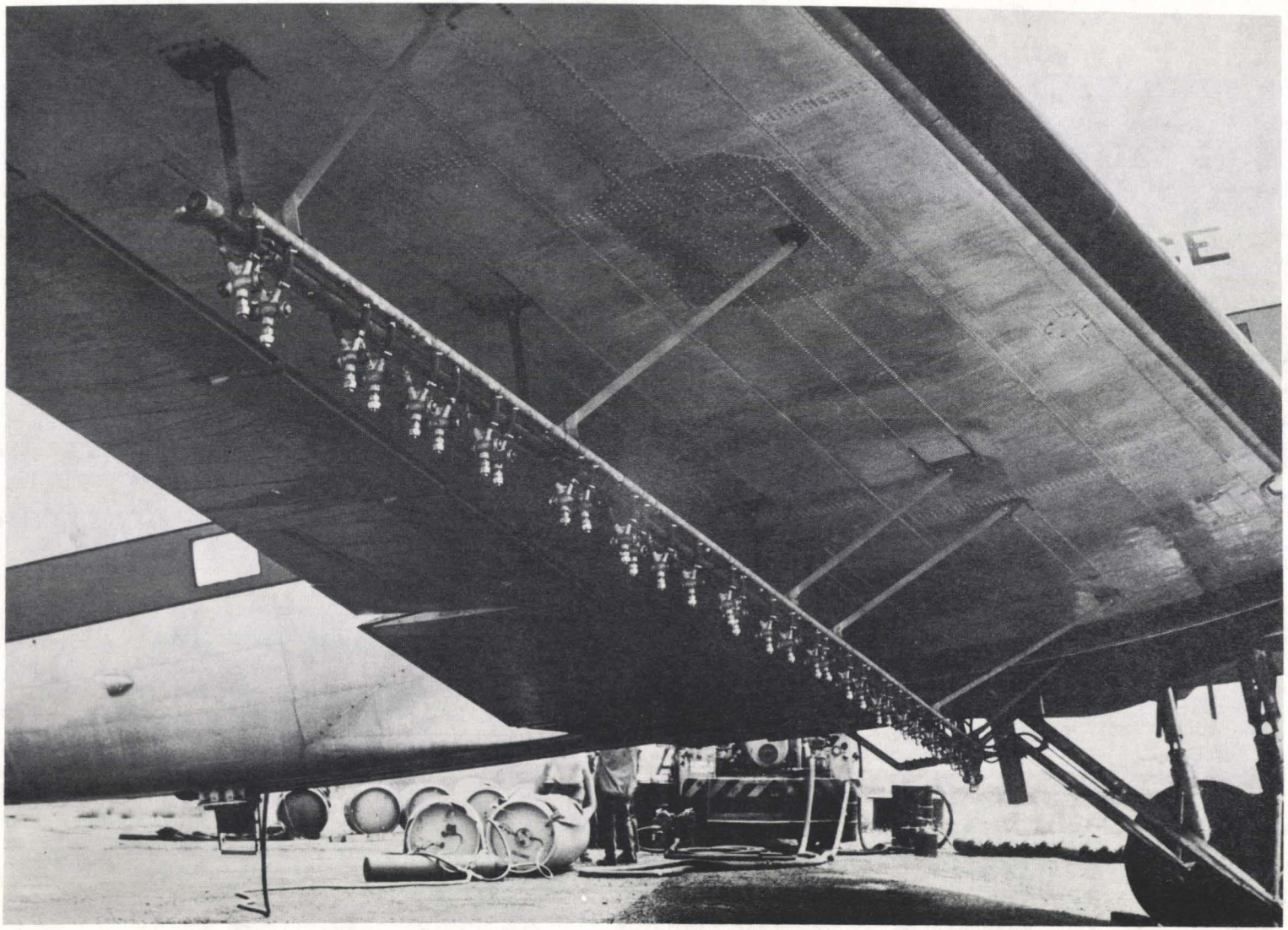
After the 1967 pilot tests, work continued to learn more about the formation of aerosols and to find a better method of producing them. To determine if the atomizing fluid "Freon-12" and the carrier "Dowanol TPM" were miscible, samples of the carrier were sent to E. I. duPont and Company. They found the carrier and atomizing fluid to be completely miscible in all proportions. A sample quantity of the insecticide solution consisting of one ounce of technical grade "Zectran" by weight in one pint of solution was then sent to E. I. duPont and Company for additional tests. It was mixed in varying proportions with the atomizing fluid and at a concentration of 60% by weight of the atomizing fluid and 40% by weight of the insecticide solution a slight precipitate formed as shown in Table V. From subsequent tests with pure "Zectran" it was determined that the precipitate was the impurities in the technical grade "Zectran". However, the quantity of impurities were so minute that they could be neglected.

Engineers at Aerosol Research Company, a manufacturer of aerosol valves for industry, indicated that having the spray solution at as high a velocity as possible just before exiting the spray tip orifice was essential in the formation of aerosol size drops.

This information confirmed what had been learned in our tests. It became very obvious as to why the bifluid nozzle had worked and the spray tip alone had not. The bifluid nozzle formed a miscible solution of the two fluids in the mixing chamber (Figure 11) and at the same time allowed the atomizing fluid to partially flash into vapor which imparted a high velocity to the solution as it left the exit orifice. Knowing that the two fluids were miscible and how an aerosol nozzle works, it became apparent that the bifluid system could be simplified once a proper nozzle was found or designed.

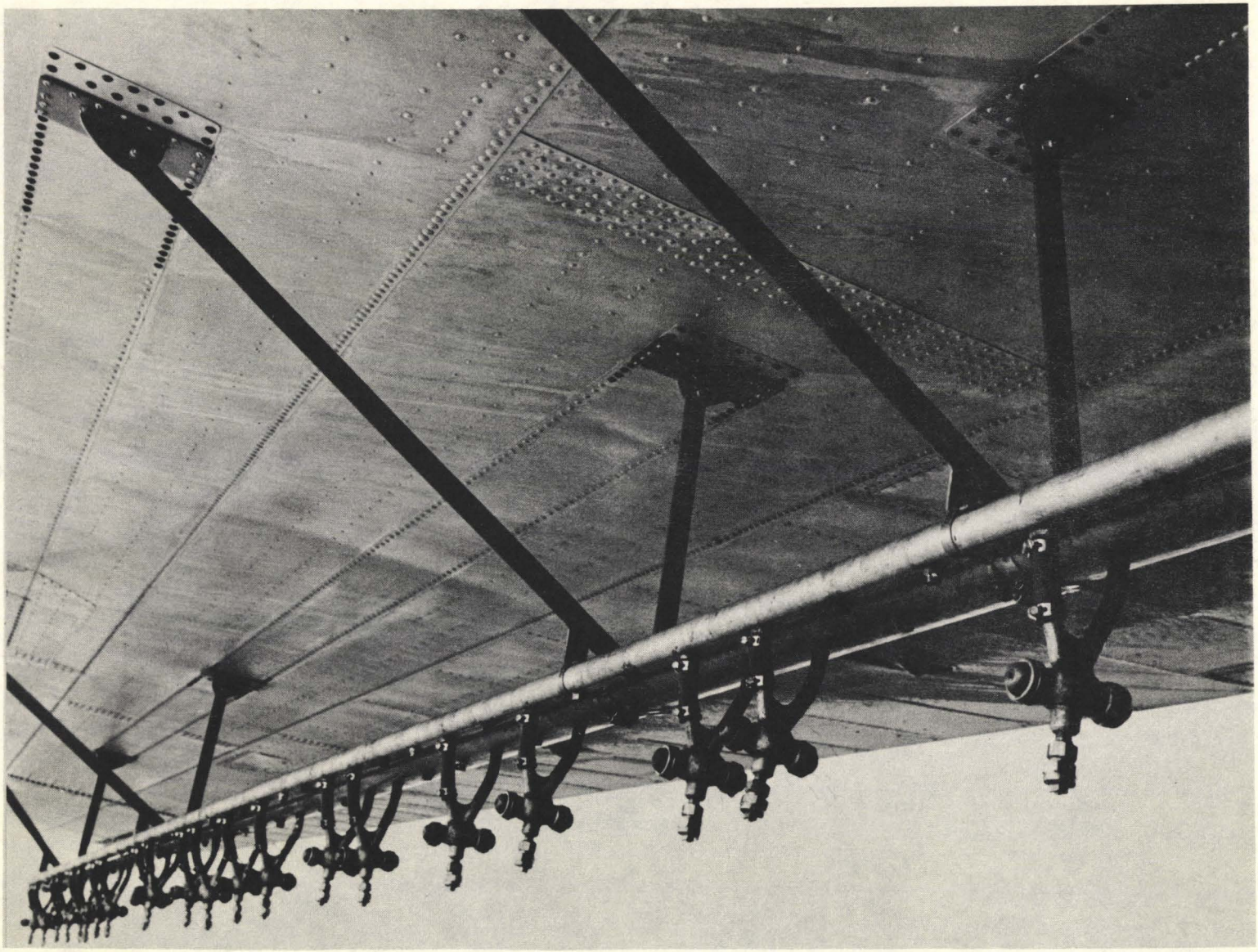
Again it was decided that because of the high cost of the atomizing fluid a spray system using more than 50% by weight of atomizing fluid would be impractical. Nozzle testing continued with a solution of 50% by weight of atomizing fluid and 50% by weight of carrier. Many commercial nozzles as well as MEDC designed nozzles were tested; however, none produced any better droplet spectrum than the Spraying Systems Company TX-26 "Cone Jet" nozzle (results of actual airplane flight tests with the TX-26 are shown in Table III). This nozzle produced approximately the same droplet size as the bifluid nozzle, with the best results when the spray pressure is two pounds above the vapor pressure of the solution.

SPRAYING WITH THE C–47 BIFLUID SPRAY SYSTEM
FIGURE 22



C–47 BIFLUID SPRAY SYSTEM SHOWING TWIN BOOM & NOZZLE INSTALLATION. FORWARD BOOM CARRIES ATOMIZING FLUID & AFT BOOM CARRIES INSECTICIDE & CARRIER

FIGURE 23

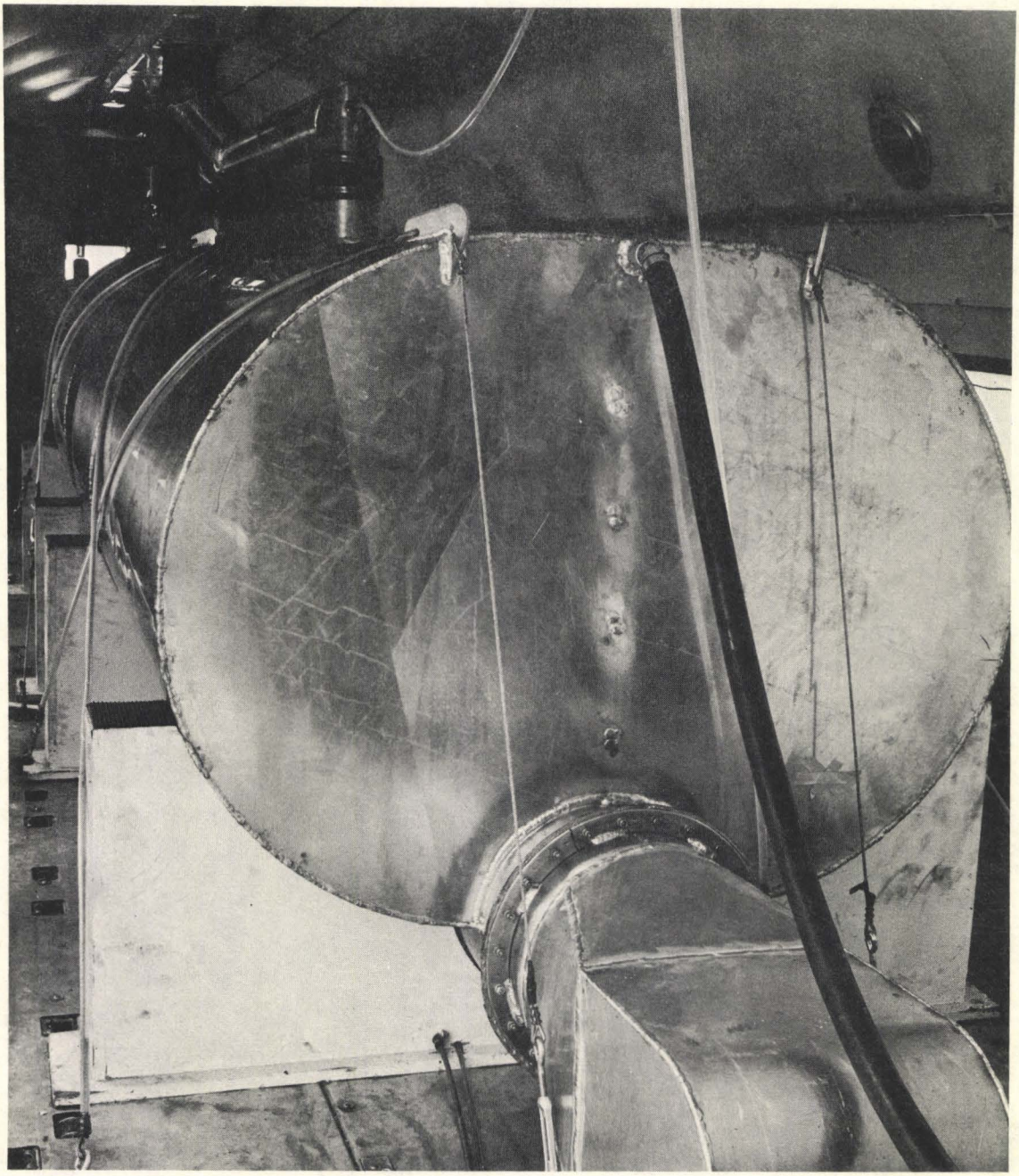


CLOSE UP VIEW OF C–47 TWIN BOOM & NOZZLE INSTALLATION

FIGURE 24

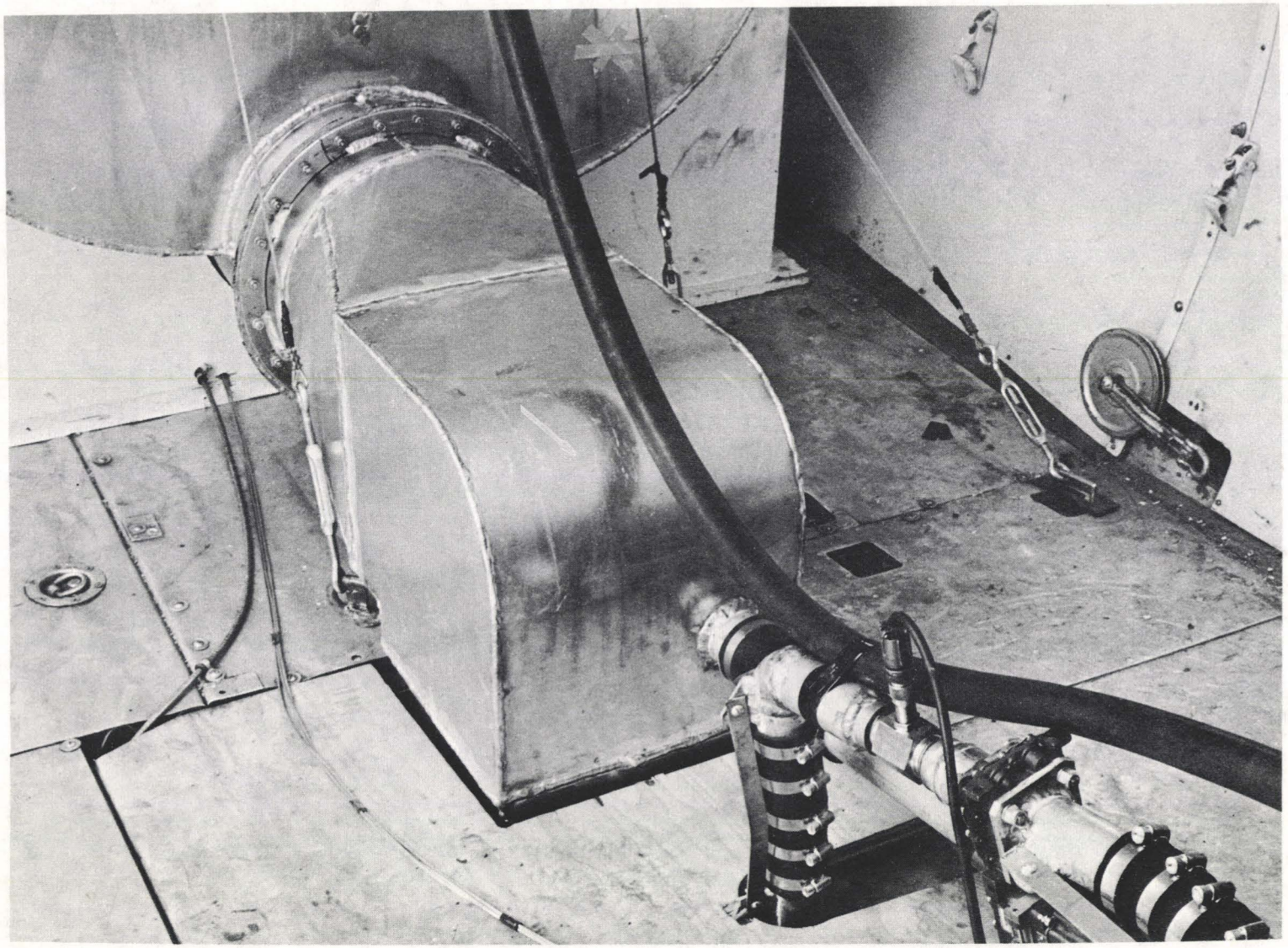
VIEW OF C–47 BIFLUID SPRAY TANKS INSIDE THE CARGO COMPARTMENT LOOKING AFT. THE SIDE OF THE ATOMIZING FLUID TANK IS IN THE FOREGROUND AND THE END OF THE INSECTICIDE TANK IS IN THE BACKGROUND WITH THE VENT TO THE OUTSIDE AT THE TOP

FIGURE 25



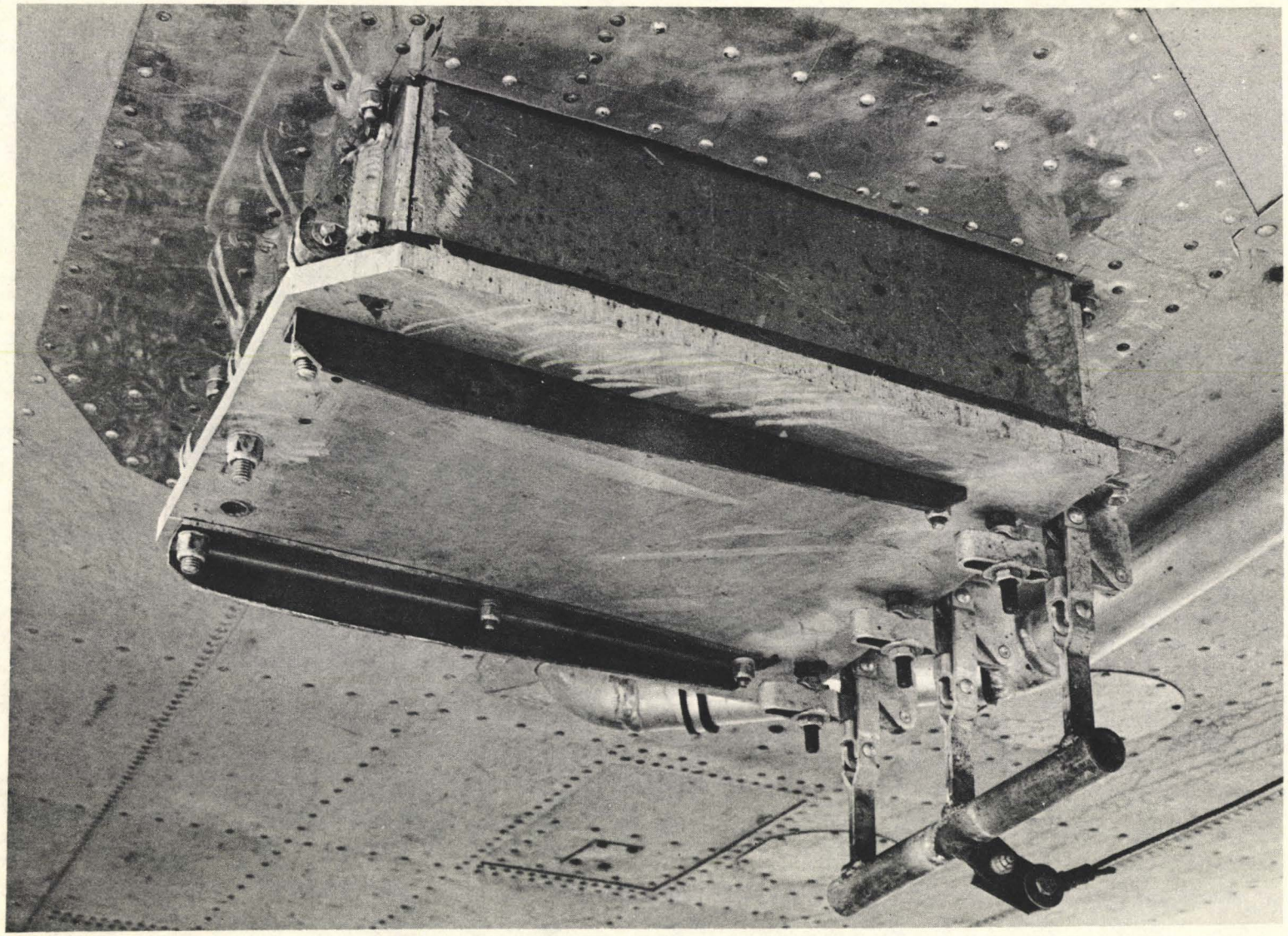
C–47 BIFLUID SPRAY SYSTEM, VIEW INSIDE CARGO COMPARTMENT LOOKING FORWARD SHOWING INSTALLATION OF INSECTICIDE TANK

FIGURE 26



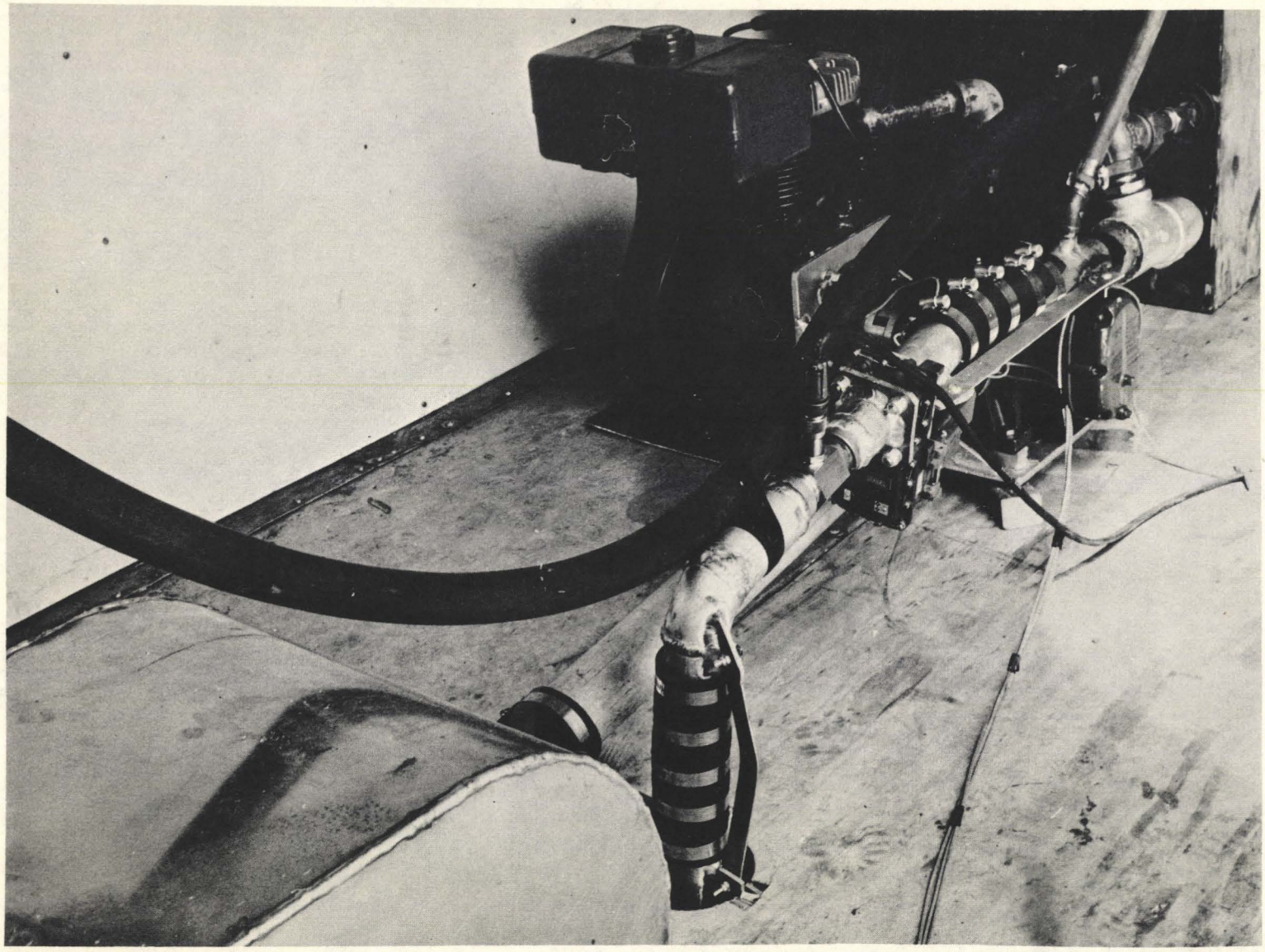
C—47 BIFLUID SPRAY SYSTEM, VIEW SHOWING INSECTICIDE TANK OUTLET TO DUMP VALVE

FIGURE 27

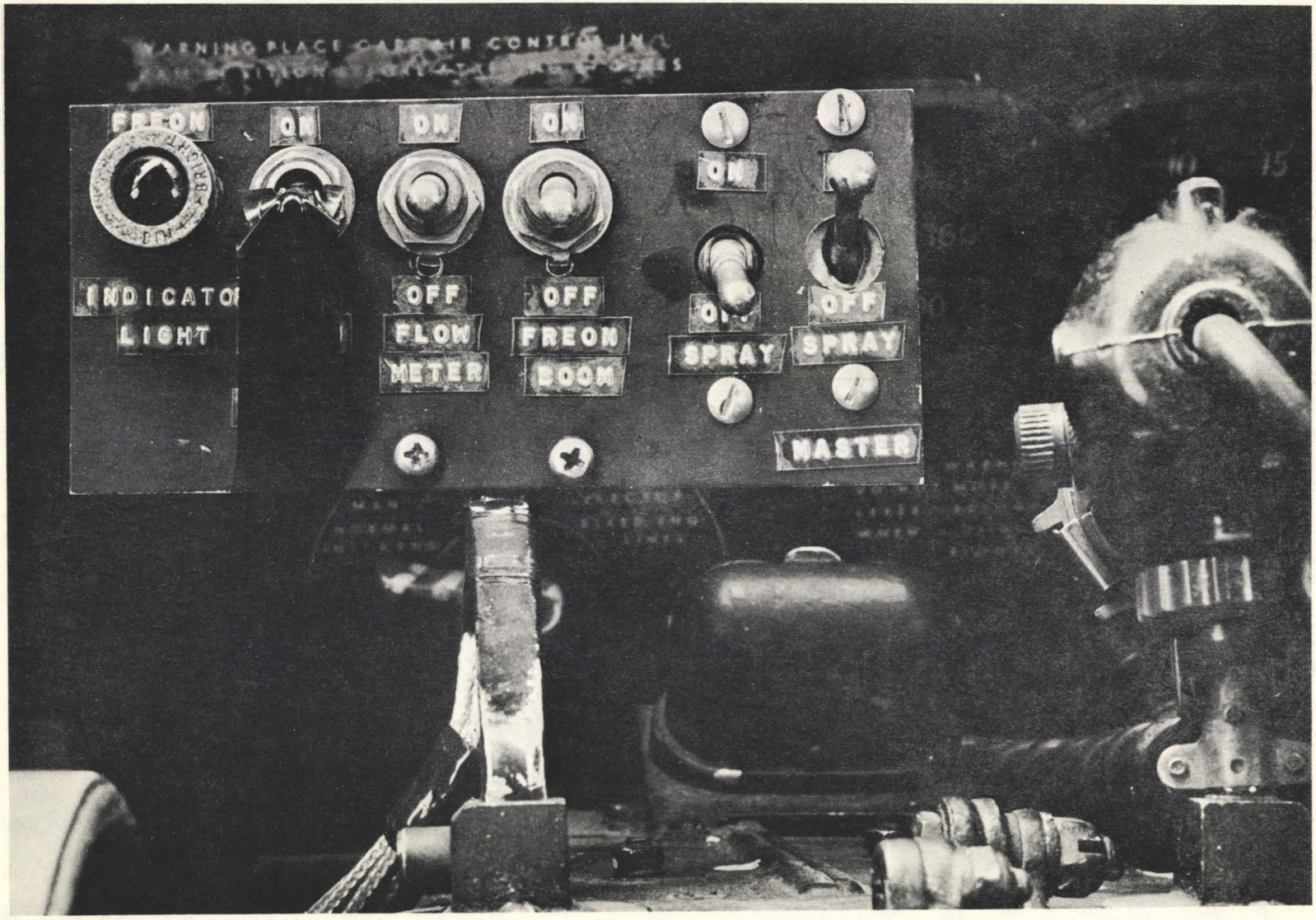


DUMP VALVE, C–47 BIFLUID SPRAY SYSTEM

FIGURE 28



GASOLINE ENGINE POWERED INSECTICIDE SPRAY PUMP, C–47 BIFLUID SPRAY SYSTEM
FIGURE 29



C–47 BIFLUID SPRAY SYSTEM, PILOT'S CONTROL PANEL
FIGURE 30

ATOMIZING FLUID CONCENTRATION (PERCENT BY WEIGHT)	10	30	40	50	60	75	90
INSECTICIDE CONCENTRATION (PERCENT BY WEIGHT)	90	70	60	50	40	25	10
VAPOR PRESSURE OF SOLUTION AT 70 DEGREES F	—	32	47	56	62	66	—
COMPATIBILTY	COMPATIBLE	COMPATIBLE	COMPATIBLE	COMPATIBLE	VERY SLIGHT PRECIPITATE	SLIGHT PRECIPITATE	PRECIPITATE

DATA OBTAINED THRU THE COOPERATION OF E. I. DUPONT & COMPANY.

TABLE V

VAPOR PRESSURE & COMPATIBILITY RELATIONSHIPS OF SPRAY SOLUTIONS AT VARIOUS CONCENTRATIONS OF ATOMIZING FLUID (FREON —12) AND INSECTICIDE (5.62 PERCENT ZECTRAN IN DOWANOL —TPM)

A spray pressure greater than the solution vapor pressure is essential to insure that the atomizing fluid does not flash into a vapor except in the expansion chamber of the nozzle as shown in Figure 31. It was not possible to measure the pressure drop across the metering passages because of the small size of the expansion chamber. The pressure at the entrance to the nozzle was varied to determine the operating pressure which produced the smallest droplets. Other spray nozzles of similar design would probably work equally well in production of small drops once the operating pressure is established. The operating pressure will vary with each type of nozzle because of the variations in the size of the metering passages, expansion chamber and exit orifice.

The TX-26 nozzle works in the same way as the bifluid nozzle except that the two fluids are already in solution. As shown in Figure 31 the spray solution enters the expansion chamber through the metering passages that are considerably smaller than the exit orifice which results in an expansion chamber pressure that is less than the vapor pressure of the solution. The atomozing fluid flashes into a vapor in the expansion chamber forming a gaseous fluid mixture that surges through the exit orifice at a high velocity. As it leaves the exit orifice it continues to expand at an explosive rate breaking up the insecticide fluid into small droplets.

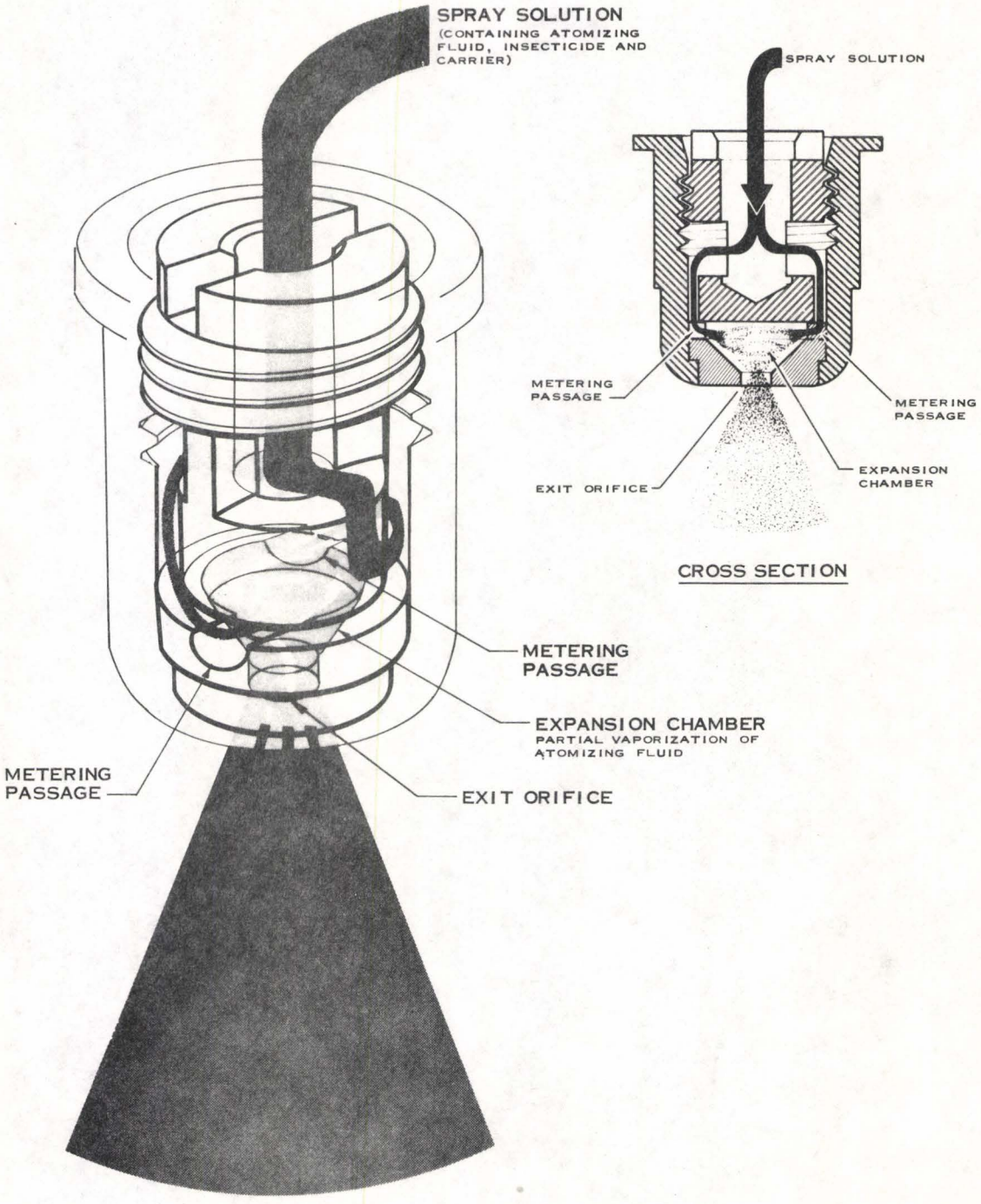
Some of the atomizing fluid (about 20% to 25%) remains in solution with the insecticide carrier fluid long after leaving the nozzle exit orifice. This was discovered during a nozzle spray test when the test chamber floor was wet with water. As the larger drops fell into the water, the water appeared to boil. It was found that the insecticide carrier fluid had a greater affinity for water than the atomizing fluid so it released the atomizing fluid as a vapor when it came in contact with water.

Not too much is known as to why some of the carrier fluid clings to the atomizing fluid. It is surmised that the two fluids are either highly compatible or the high surface tension of the carrier fluid retains the atomizing fluid. The latter appears to be the most feasible because the solution vapor pressure of the carrier and atomizing fluid is less than the vapor pressure of the atomizing fluid by itself.

To increase the efficiency of the atomizing fluid, all of it will have to be released as a vapor. Perhaps an additive that will reduce the surface tension of the carrier fluid will accomplish this. This problem will need further study and testing to arrive at a solution.

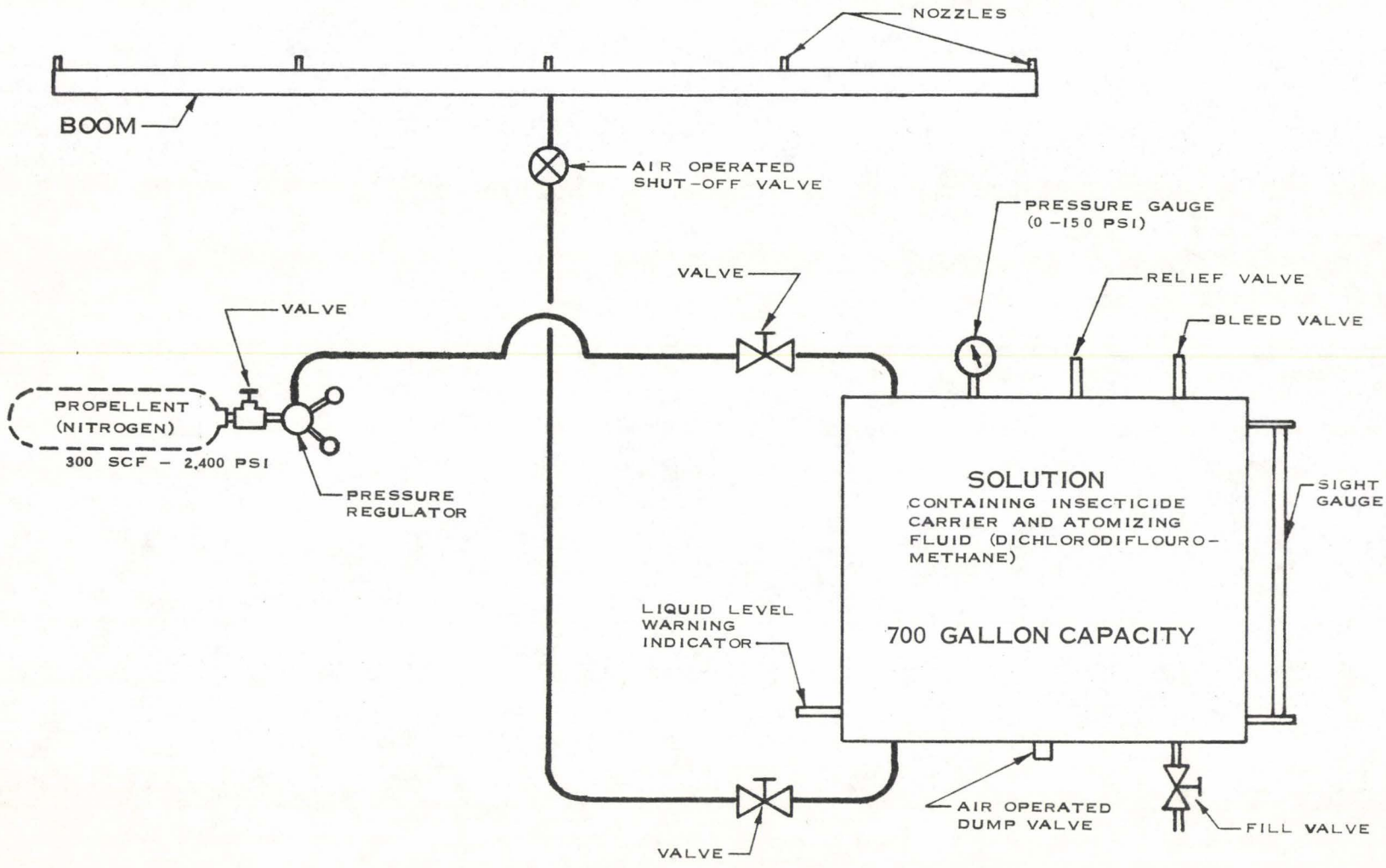
DESIGN DESCRIPTION OF THE C-47 SOLUTION SPRAY SYSTEM

When it was found that the TX-26 spray nozzle produced droplets of the same size as the bifluid spray system and because of the high drag forces of the bifluid spray boom, it was decided that the C-47 bifluid system would be replaced with a solution system as shown in Figure 32. The



SPRAYING SYSTEMS COMPANY
TX-26 SPRAY NOZZLE

FIGURE 31



C-47 INSECTICIDE SPRAY SYSTEM
(SOLUTION SYSTEM)

FIGURE 32

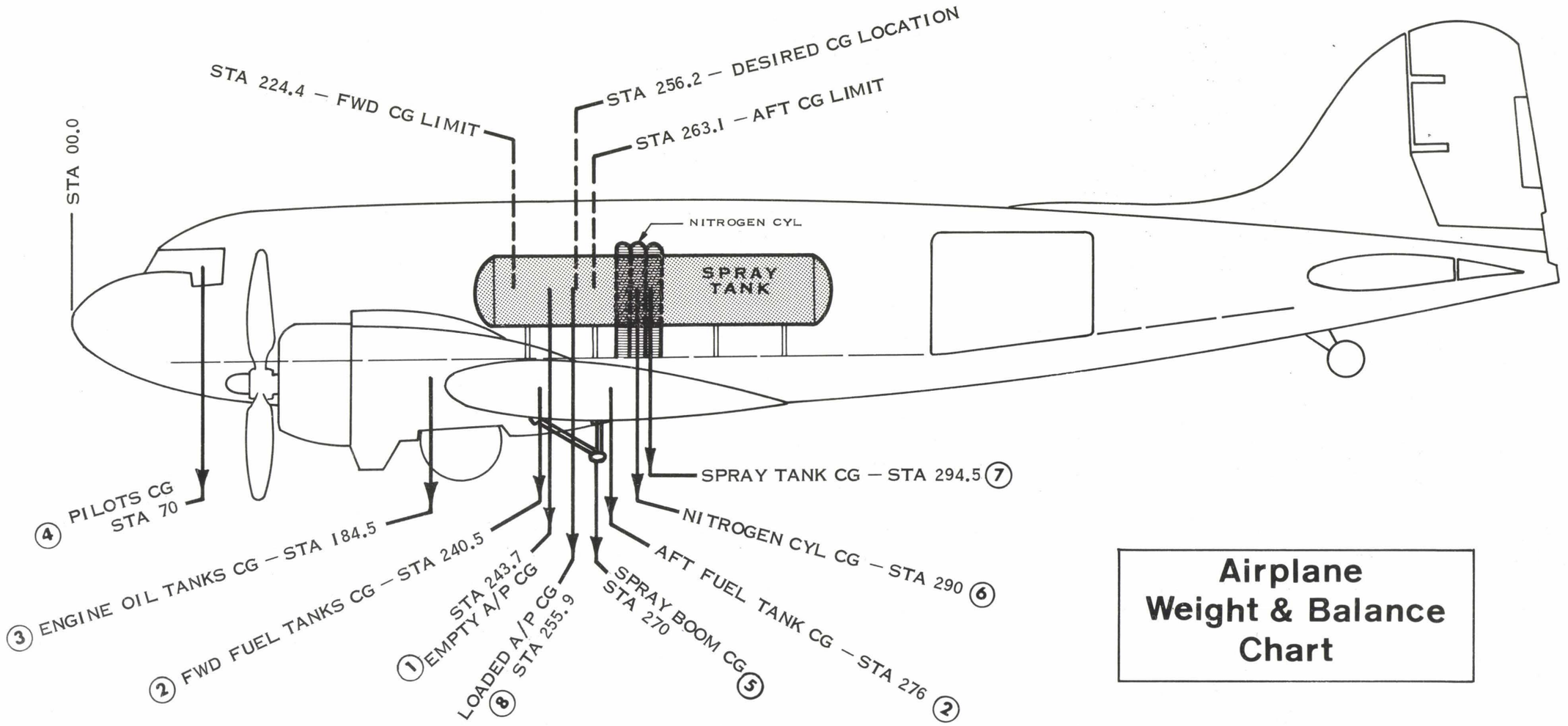
C-47, thus equipped, was to be operational for the 1968 pilot tests and would be the only airplane used.

In the preliminary design of the system, the first step was to determine the maximum capacity and weight of the system without exceeding the allowable gross weight of the airplane. From the Airplane Operation and Performance Manual and discussions with the pilots concerning probable flying conditions, the allowable gross weight for the C-47 was set at 29,500 pounds. As the empty weight of the airplane was 18,250 pounds the useful load became 11,250 pounds. From this the weight of the fuel, oil, and pilots was deducted which resulted in 8,210 pounds as the weight of the spray system (for the actual airplane weight and balance chart see Table VI). If it is desired to reduce the gross weight of the airplane, the fuel load or amount of solution can be reduced. Important considerations in the design were to stay within the weight limits, keep the system simple, minimize drag, and keep to a minimum the number of modifications required on the airplane.

The tank is made of aluminum and is designed and fabricated to meet the ASME Unfired Pressure Vessel Code, with a design working pressure of 100 psig at a temperature of 100°F. It has a capacity of 700 US gallons with outlets provided as shown in Figure 33 (MEDC Drawing 209A). Figure 34 shows the tank installed in the airplane. It has an empty weight of approximately 850 pounds.

To facilitate maneuvering the tank to its desired location inside the airplane, retractable casters are provided on the end bunks. The tank and associated equipment was located in the airplane so that the center of gravity location of the fully loaded airplane was within the allowable airplane CG limits. For calculations showing the final CG location of the airplane see the Airplane Weight and Balance Chart, Table VI.

Five bunks are used to distribute the weight of the tank and contents on the cargo floor as shown in Figure 34. The cargo floor distributes the weight over the floor beams which in turn transmit the load into the fuselage. Because of the concentrated loading in the immediate area of the tank (7,600 pounds), the possibility of floor beam failure was investigated. As no information was available in the Maintenance and Operation Manuals on the allowable floor beam loading, McDonnell Douglas Corporation was contacted. They gave the design load for the floor beams as 3,500 pounds each. Assuming that each of the five bunks take 1/5 of the load (7,600/5 = 1,520 pounds), then each bunk would transmit 1,520 pounds to each floor beam. To distribute the tank weight equally on each bunk and thus to the floor, the base of the bunks are shimmed until the cradle cushioning pad is compressed equally on each bunk. To accomplish this, the forward and aft bunks can be raised on the retractable casters so that shims can be installed under the bunks requiring it. All equipment in the airplane is secured to withstand a 9G crash landing load as prescribed by Federal Aviation Administration regulations. The tank is secured to the airplane floor by 3/16" diameter, 7 x 19 aircraft cable which has an ultimate strength of 4,200 pounds. Twelve tie down lugs are provided on the


STA 00.0
STA 224.4 — FWD CG LIMIT
STA 256.2 — DESIRED CG LOCATION
STA 263.1 — AFT CG LIMIT
NITROGEN CYL
SPRAY TANK
SPRAY TANK CG — STA 294.5 (7)
NITROGEN CYL CG — STA 290 (6)
AFT FUEL TANK CG — STA 276 (2)
SPRAY BOOM CG (5)
STA 270
STA 243.7
EMPTY A/P CG (1)
LOADED A/P CG
STA 255.9 (8)
(4) PILOTS CG
STA 70
(3) ENGINE OIL TANKS CG — STA 184.5
(2) FWD FUEL TANKS CG — STA 240.5

Airplane Weight & Balance Chart

AIRPLANE LOADING

(1)	EMPTY WT OF AIRPLANE	18,250 LB	
	CG — STA 243.7 (18,250 LB X 243.7 IN)		4,447,525 IN LB
(2) FUEL	200 GAL FWD TANK AT 6 LB PER GAL	1,200 LB	
	CG — STA 240.5 (1,200 LB X 240.5 IN)		288,600 IN LB
	200 GAL AFT TANK AT 6 LB PER GAL	1,200 LB	
	CG — STA 276.0 (1,200 LB X 276.0 IN)		331,200 IN LB
(3)	OIL — 40 GAL AT 7 LB PER GAL	280 LB	
	CG — STA 184.5 (280 LB X 184.5 IN)		51,660 IN LB
(4)	PILOT AND CO-PILOT	400 LB	
	CG — STA 70 (400 LB X 70 IN)		28,000 IN LB
(5)	SPRAY BOOMS	160 LB	
	CG — STA 270 (160 LB X 270 IN)		43,200 IN LB
(6)	NITROGEN CYLINDERS	490 LB	
	CG — STA 290 (490 LB X 290 IN)		142,100 IN LB
(7)	SPRAY TANK, CONTENTS & ACCESSORIES	7,600 LB	
	CG — STA 294.5 (7,600 LB X 294.5 IN)		2,238,200 IN LB
	GROSS WEIGHT	29,580 LB	
	TOTAL MOMENT		7 570,485 IN LB

$$\text{LOADED CG} = \frac{\text{TOTAL MOMENT}}{\text{GROSS WEIGHT}}$$

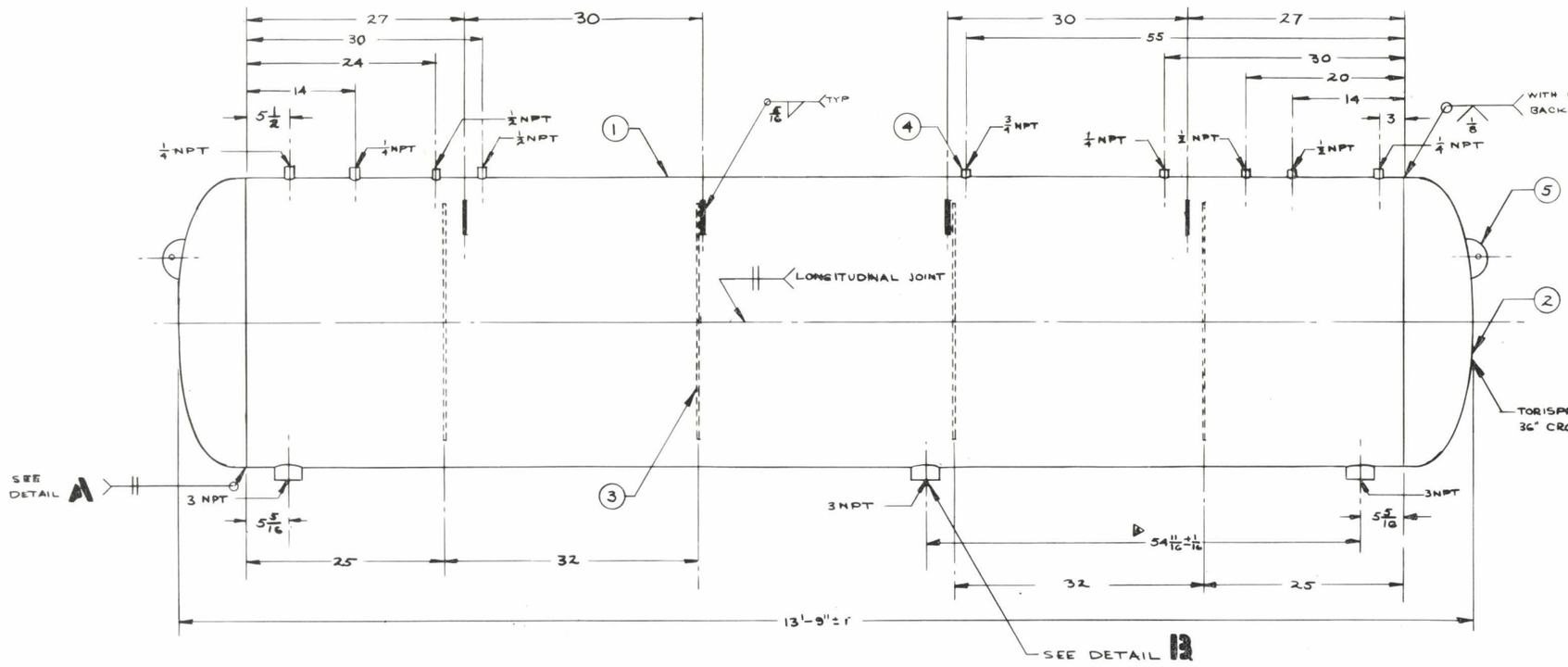
$$\frac{7,570,485}{29,580} = 255.9 \text{ IN } (8)$$

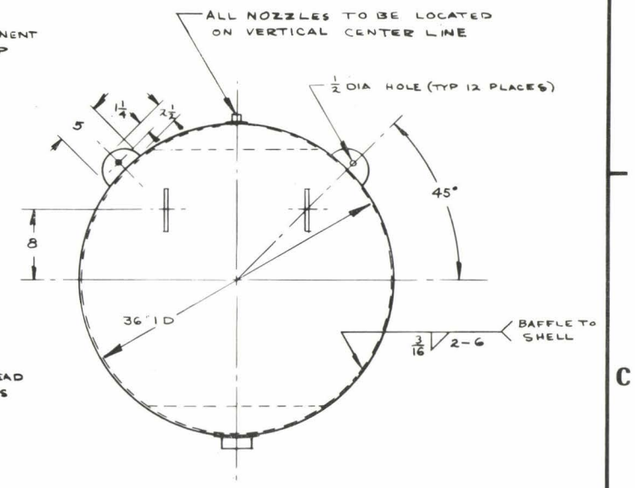
U.S. FOREST SERVICE EQUIPMENT DEVELOPMENT CENTER, MISSOULA, MONTANA

TABLE VI

MATERIALS LIST

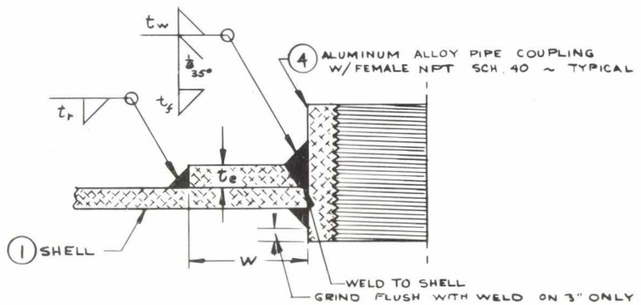
NO	PART NAME	REQD	MATERIAL-DESCRIPTION	SHEET
1	SHELL	1	5/16 THICK 5086 ALUMINUM ALLOY PLATE	
2	HEADS	2	5/16 THICK 5086 ALUMINUM ALLOY (SEE NOTE 1)	
3	BAFFLES	4	1/4 THICK ALUMINUM ALLOY PLATE	
4	NOZZLES	A/R	SEE DETAIL B	
5	TIE DOWNS	12	5/16 THICK 5086 ALUMINUM ALLOY PLATE	





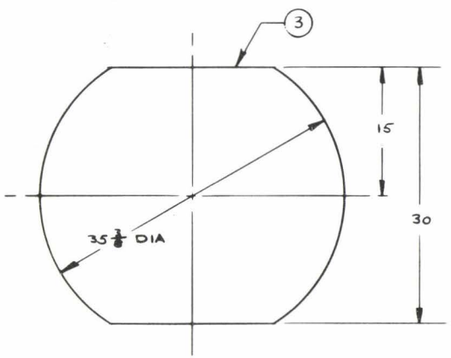
NOTES:

1. TORISPHERICAL HEAD SHALL HAVE A KNUCKLE RADIUS EQUAL TO 6% THE CROWN RADIUS, SKIRT LENGTH SHALL BE THREE (3) TIME THICKNESS OF HEAD + 1/2".
2. ALL MATERIALS, FABRICATION, & WORKMANSHIP SHALL CONFORM TO THE ASME UNFIRED PRESSURE VESSEL CODE, HOWEVER VESSEL NEED NOT BE LABELED.
3. TANK SHALL BE OF ALL WELDED CONSTRUCTION WHICH SHALL BE ACCOMPLISHED BY A CERTIFIED ALUMINUM WELDER.
4. TANK SHALL BE CLEANED OF ALL FOREIGN MATERIAL.
5. TANK SHALL BE HYDROSTATICALLY TESTED TO A PRESSURE OF 150 PSIG & THE 150 PSIG PRESSURE SHALL HOLD FOR ONE HOUR WITH ZERO PRESSURE DROP. HYDROSTATIC TEST WILL BE OBSERVED BY A REPRESENTATIVE OF THE U.S. FOREST SERVICE & SHALL BE NOTIFIED FIVE(5) DAYS PRIOR TO TEST DATE.

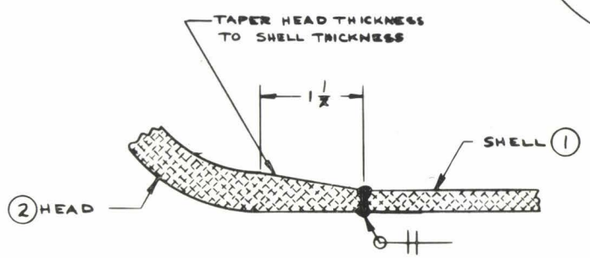


SIZE	QTY	REINF'G PAD		WELDS		
		w	te	t_f	t_r	t_w
3"	3	1 3/4	5/16	5/16	3/16	3/16
3/4"	1	9/16	5/16	1/8	1/8	1/8
1/2"	4	7/16	5/16	1/8	1/8	1/8
1/4"	4	5/16	5/16	1/8	1/8	1/8

DETAIL B
FULL SCALE



BAFFLE



DETAIL A
FULL SCALE

4-69	REMOVE 60" DIMENSION & ADD 54 11/16 ± 1/16 DIMENSION BETWEEN ℄ OF OUTLETS	EWL
DATE	REVISION	BY

UNLESS OTHERWISE SPECIFIED
TOLERANCES:
FRACTIONS ± 1/8
DECIMALS ±
ANGLES ± 1°
DIMENSIONS ARE IN INCHES
BREAK SHARP EDGES

U.S. DEPT. OF AGRICULTURE
FOREST SERVICE
EQUIPMENT DEVELOPMENT CENTER
MISSOULA, MONTANA

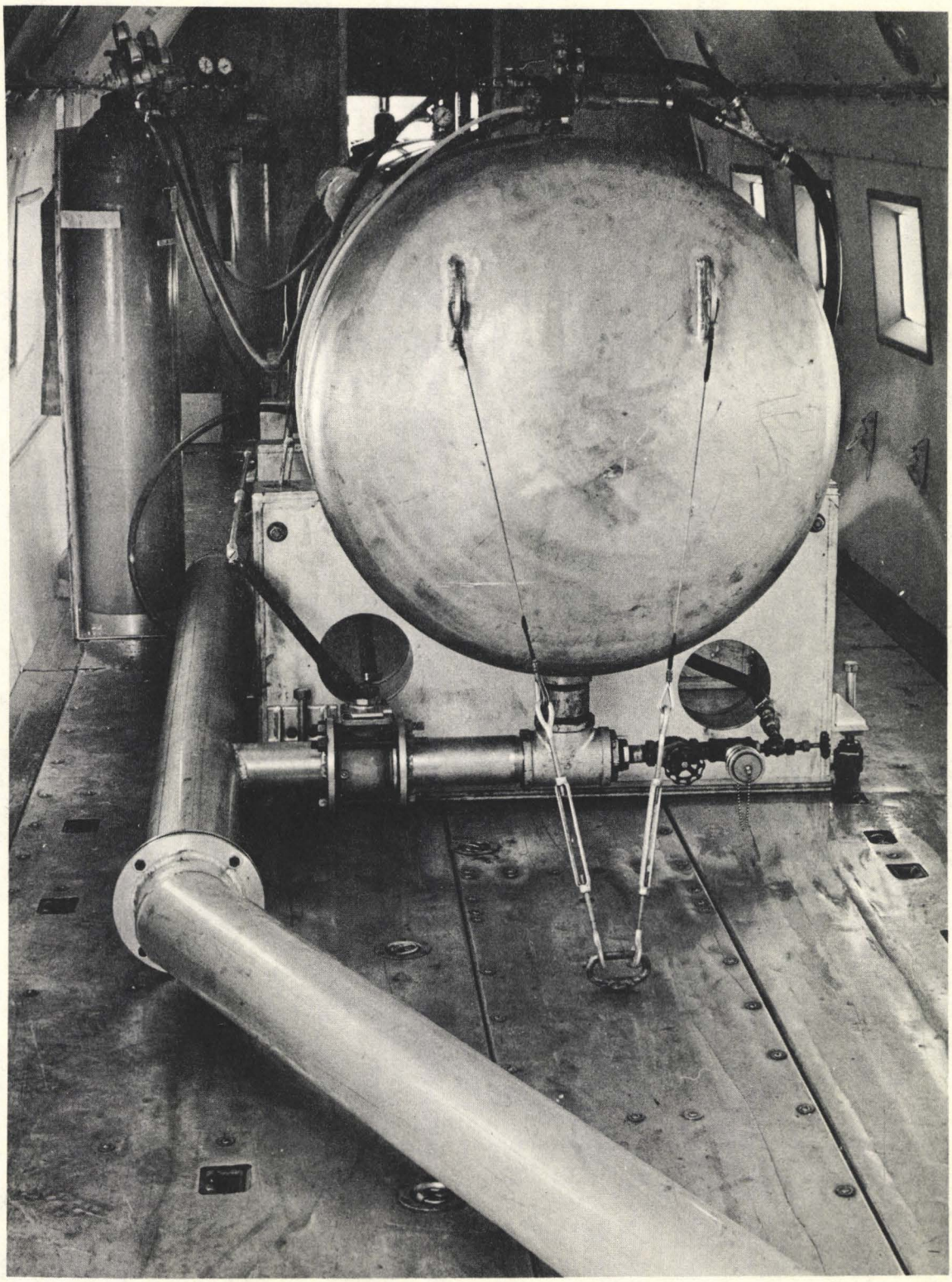
DRAWN	LASSILA
DESIGNED	JASUMBACK
CHECKED	
APPROVED	
SCALE	1 ℄ = 1 ℄ NOTED
DATE	NOV. 1968

TITLE
AIRCRAFT SPRAY TANK 700 GAL
TORISPHERICAL HEAD

SHEET 1 OF 1

MEDC-409A

FIGURE 33



INSIDE VIEW OF C–47 SHOWING THE SOLUTION SYSTEM TANK

(NOTE – ROLLERS ON BUNK, 6 INCH DIAMETER EMERGENCY DISCHARGE DUCT ON FLOOR, AND THE TIE DOWN ON REAR OF TANK)

FIGURE 34

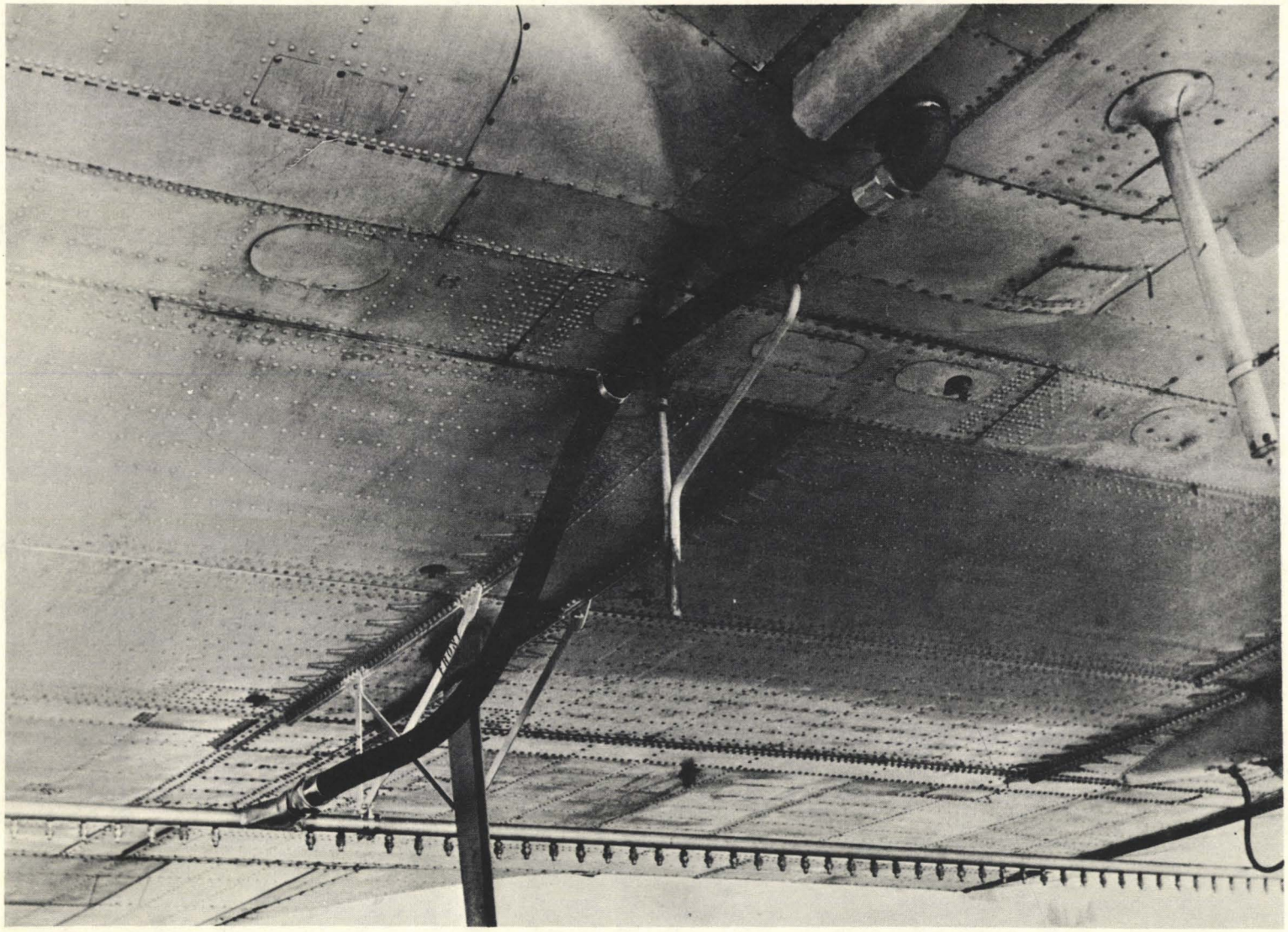
tank (four on each side and two on each end) to which the cables are attached and anchored to existing cargo floor tie down hooks as shown in Figure 34. By the use of the existing cargo floor hooks the tank can be installed easily with no modification to the airplane.

The boom is 65 feet long with 250 1/8" NPT threaded holes spaced at three inch intervals. It is made of aluminum alloy and has a symmetrical airfoil shape to keep weight and drag at a minimum. It consists of a center and two outboard sections and is attached to the wing by use of existing nutplates and screws; thus no modification to the airplane is required. The center section boom is attached to the fuel tank cover attach angles as shown in Figure 35 and to the center wing to outer wing joint attach angles by using 1/8" longer bolts at each attach point. The outboard booms are mounted to the underside of the wing as shown in Figure 36 using 1/8" longer screws and existing nutplates provided in the wing access panels. Attaching the boom to the airplane is an easy task and requires no modifications to the wing. The boom can be rotated in the clamps to minimize drag.

In the event of an emergency, the contents of the tank can be dispensed rapidly through a six inch diameter duct that terminates outside the fuselage as shown in Figures 34 and 37. Two three inch outlets from the tank are connected to the six inch duct through two three inch ball valves that are actuated by air cylinders operated with compressed nitrogen. The system is actuated electrically from a control panel (Figure 38) located in the cockpit or by a manual pull cable also located in the cockpit within easy reach of either the pilot or copilot.

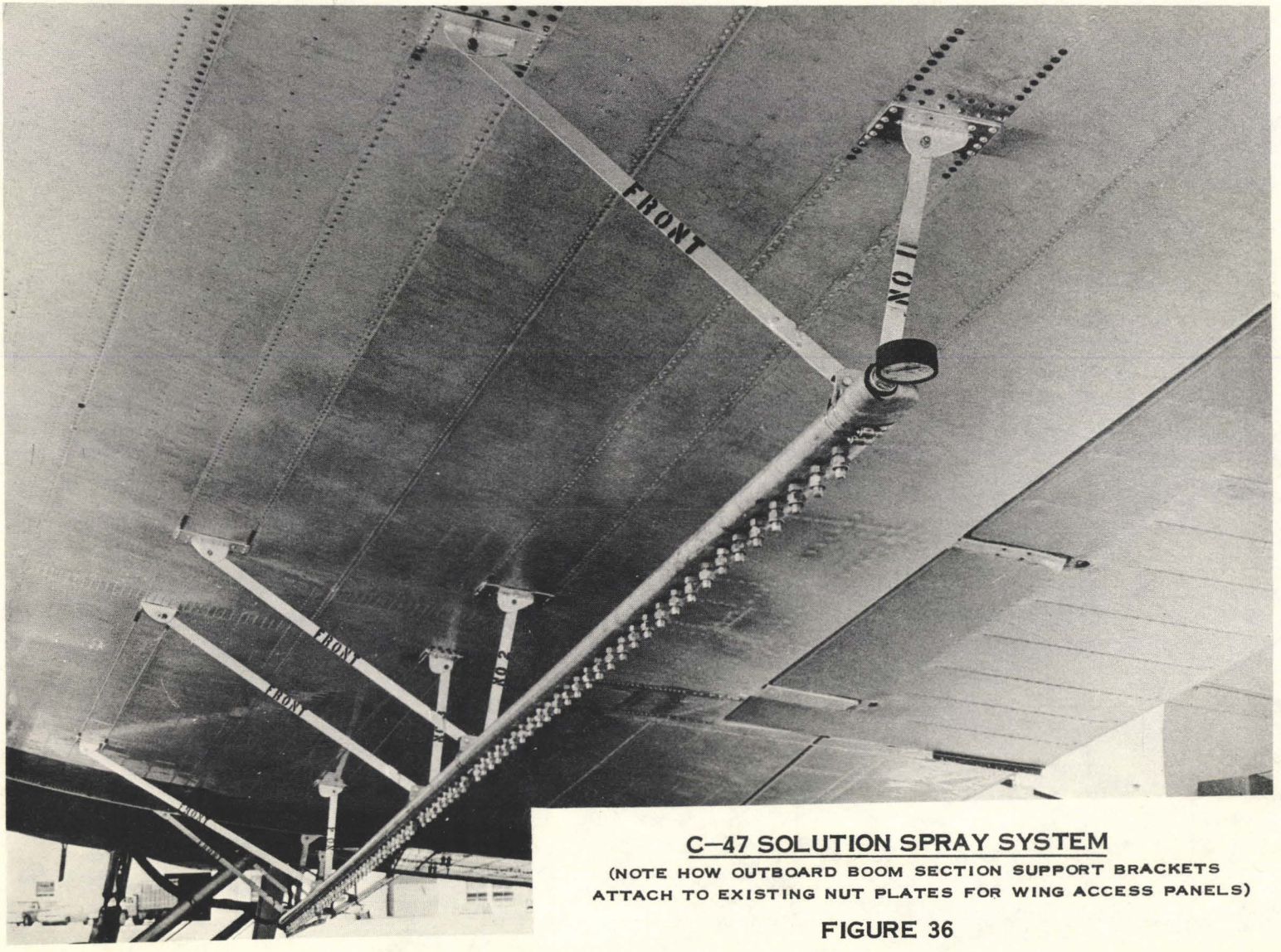
According to calculations and manufacturers test data, each three inch ball valve will discharge 1,000 gpm of water with a 5 psi pressure drop across the valve. The two valves should discharge 2,000 gpm or empty the 700 gallon tank in 21 seconds. This value of the dispensing time should be fairly accurate. It is not possible to calculate the discharge time accurately because the solution is a two phase fluid consisting of a gas and liquid phase in varying proportions. The cost in materials for actually dispensing a load to determine the discharge time would be approximately $2,000 which is quite costly. The FAA requirements state only that the system be capable of dispensing one half the load in 45 seconds with no requirements on how the system should be actuated. To meet these FAA requirements the system would have to dispense only 600 gpm which is considerably less than our anticipated rate of 2,000 gpm.

The system had been tested at 150 psig so the likelihood for a leak is improbable. However, to be sure that no fumes will collect inside the airplane if a leak does occur, a vent to the outside of the airplane was installed. The vent is located above the tank and consists of a 15^{o} bias duct six inches in diameter extended through the skin of the fuselage with the bias facing aft. Air passing over the bias creates a low pressure in the duct, resulting in venting of the cargo compartment. This provides ventilation at all times and if a leak does occur the resulting vapors will be drawn out through the vent. Installation of the vent requires a



C—47 SOLUTION SPRAY SYSTEM, VIEW AFT SHOWING CENTER BOOM SECTION ATTACHED TO THE FUEL TANK COVER ATTACH ANGLES, AND FEED LINE FROM THE TANK TO BOOM

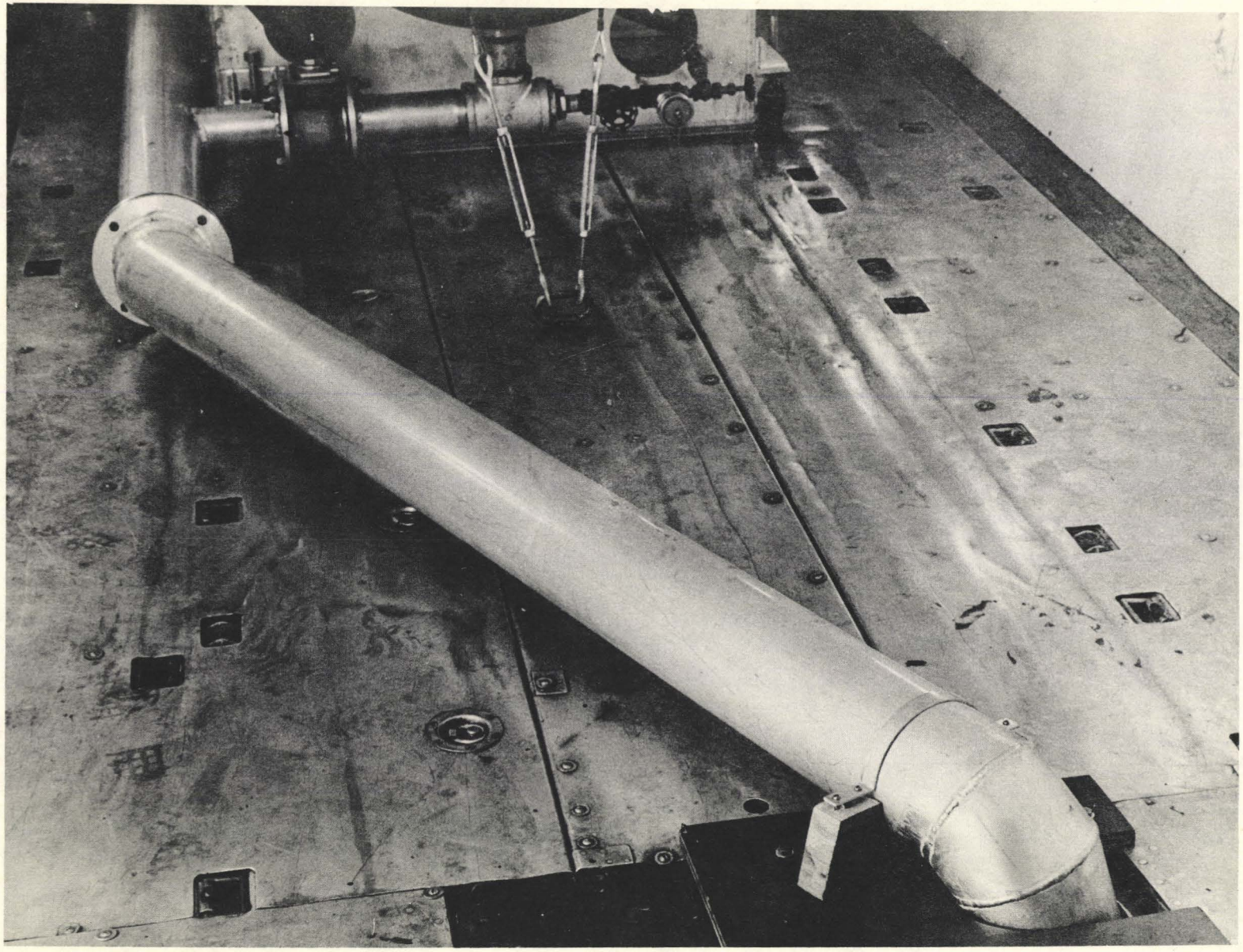
FIGURE 35



C–47 SOLUTION SPRAY SYSTEM

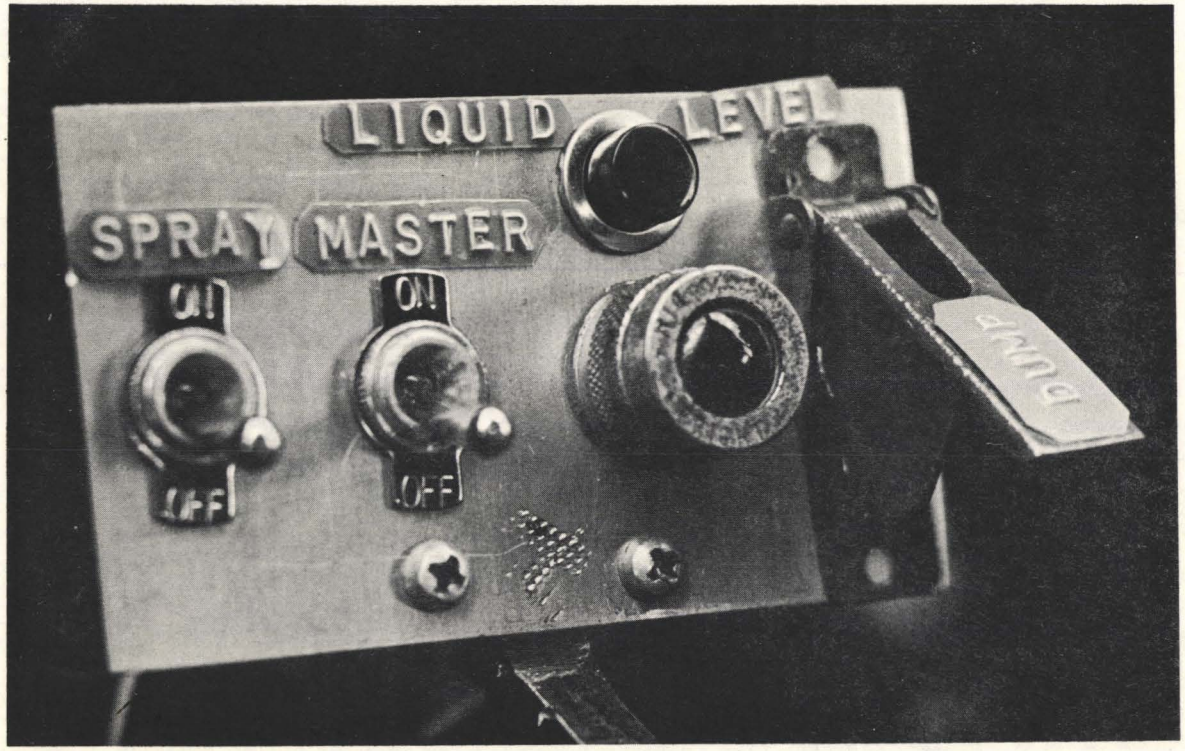
(NOTE HOW OUTBOARD BOOM SECTION SUPPORT BRACKETS ATTACH TO EXISTING NUT PLATES FOR WING ACCESS PANELS)

FIGURE 36



C–47 SOLUTION SPRAY SYSTEM EMERGENCY DISCHARGE DUCT

FIGURE 37



C-47 SOLUTION SPRAY SYSTEM CONTROL PANEL
MOUNTED ON THE AIRPLANE CONTROL CONSOLE

FIGURE 38

hole through the skin of the fuselage which must be reinforced so that the skin panel in the area of the hole is not weakened and will continue to carry its share of the skin shear.

By using existing attach points, installation of the spray system is relatively easy with a minimum number of modifications to the airplane. The only modifications required is the cutting of two six inch diameter holes in the skin for the emergency discharge duct and vent and a 2½ inch diameter hole in the skin for the supply line from the tank to the boom as shown in Figure 35. Because of its size and location it is not necessary to reinforce the 2½ inch diameter hole. The two six inch diameter holes are reinforced to prevent weakening of the skin panel; a doubler is used for reinforcement.

To obtain the most efficient atomization, the pressure in the boom and the pressure drop across the nozzles must be controlled within close limits. The pressure drop across the nozzles will vary with the vapor pressure of the solution. Because of this, the atomizing fluid was not used as both a propellant and atomizer as it is in small spray dispensers.

If it had been used as a prepellant, the vapor pressure of the solution would have dropped as it was being dispensed because the atomizing fluid would cool the solution as it flashed into vapor to fill the vacant space left by the dispensed fluid. The tank pressure and the pressure drops across the nozzles would keep decreasing, resulting in progressively inefficient atomization. Therefore, a gas must be metered into the tank to provide the propellant pressure, occupy the space left by the dispensed fluid, and thus maintain the solution vapor pressure constant. Nitrogen was selected because it is inert, readily available and economical.

The tank is pressurized above the solution vapor pressure with nitrogen metered by a pressure regulator from a 3,000 psig bottle. The boom pressure is maintained at 2 psig above the solution vapor pressure under full flow conditions. A pressure gage located on the forward bulkhead of the cargo compartment indicates the boom pressure. The tank pressure is set to maintain the required boom pressure. Once the adjustment is made, no further adjustments are necessary as long as the temperature of the spray solution is maintained within 10°F.

A panel located on the cockpit console for easy access by either the pilot or copilot is provided for complete operational control of the spray system as shown in Figure 38. A master switch with a visual indicating light is provided on this panel for control of all electrical input to the spray system. The spray control switch turns the spray on and off by activating a nitrogen gas operated valve located in the feed line between the tank and boom as shown in Figure 39. A liquid level indicating light on the panel comes on automatically to alert the pilot when the spray tank is empty. The dump switch located on the panel can be activated in case of an emergency to rapidly empty the contents of the tank, thereby greatly

reducing the weight of the airplane. A protective cover for the switch is provided to prevent inadvertent activation of the system and dispensing the contents of the tank. From this control panel the pilot or copilot has immediate and complete control of the spray system.

Figures 40 and 41 show the C-47 solution spray system in operation.

Complete fabrication and installation drawings are available for the system. They can be obtained from the Missoula Equipment Development Center.

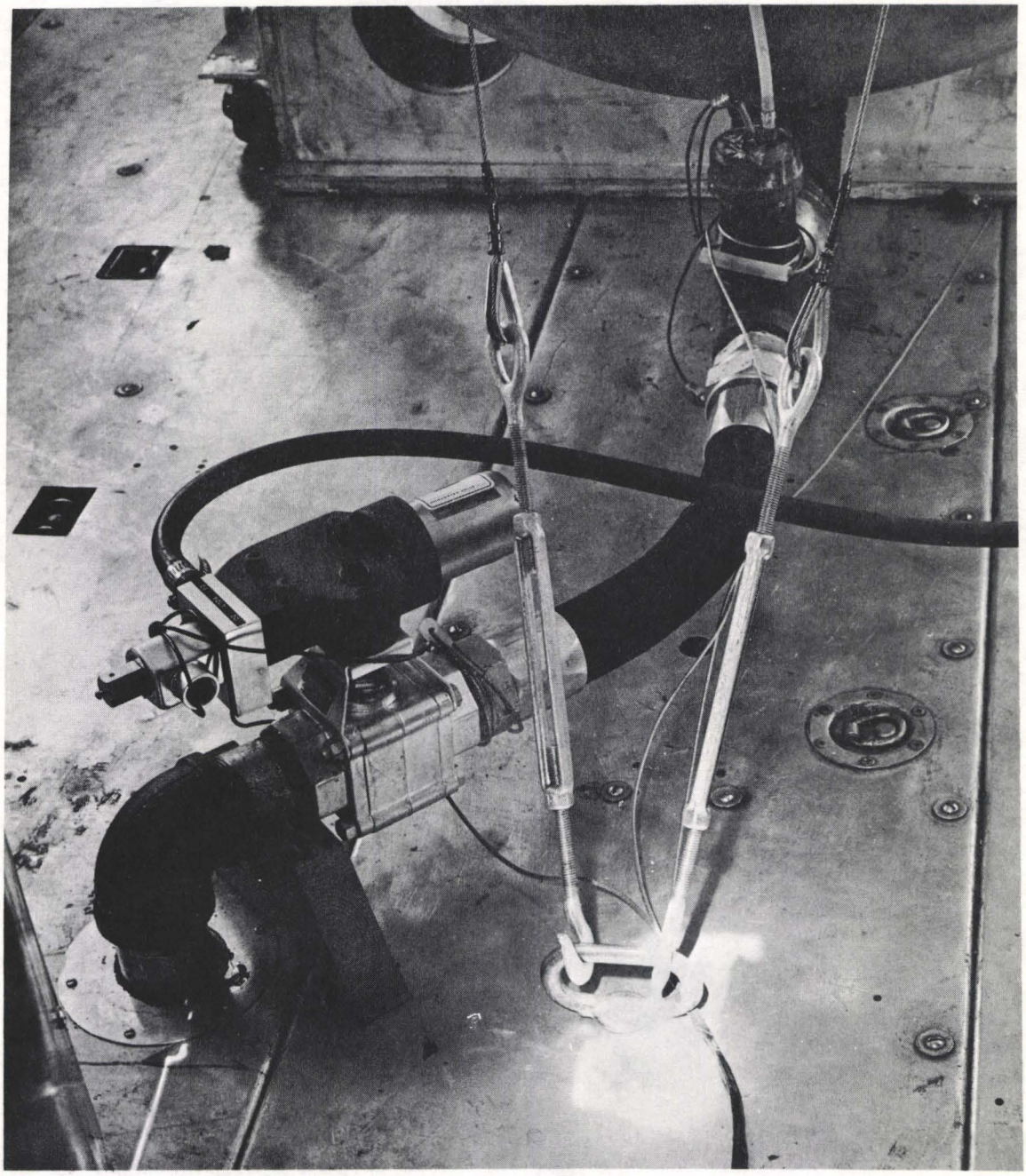
C-47 SOLUTION SYSTEM CAPACITY AND APPLICATION RATES

The original concept in application was to dispense all the insecticide spray in the bottom of a drainage below an atmospheric temperature inversion and let the air currents, resulting from the collapse of the inversion, carry the spray up the slopes (see Figures 1 and 2). During the 1968 pilot tests, only very weak temperature inversions formed over the spray area so it was decided to spray it by swathing. It was necessary to reduce the flow rate which was accomplished by decreasing the number of nozzles on the boom.

Subsequently it was decided to provide a boom with a selective flow rate that could be changed in flight. The boom is separated into four incremental sections by shut-off valves that are controlled by the pilot by a selector switch located on the spray system control panel. It has six flow rate selections as follows:

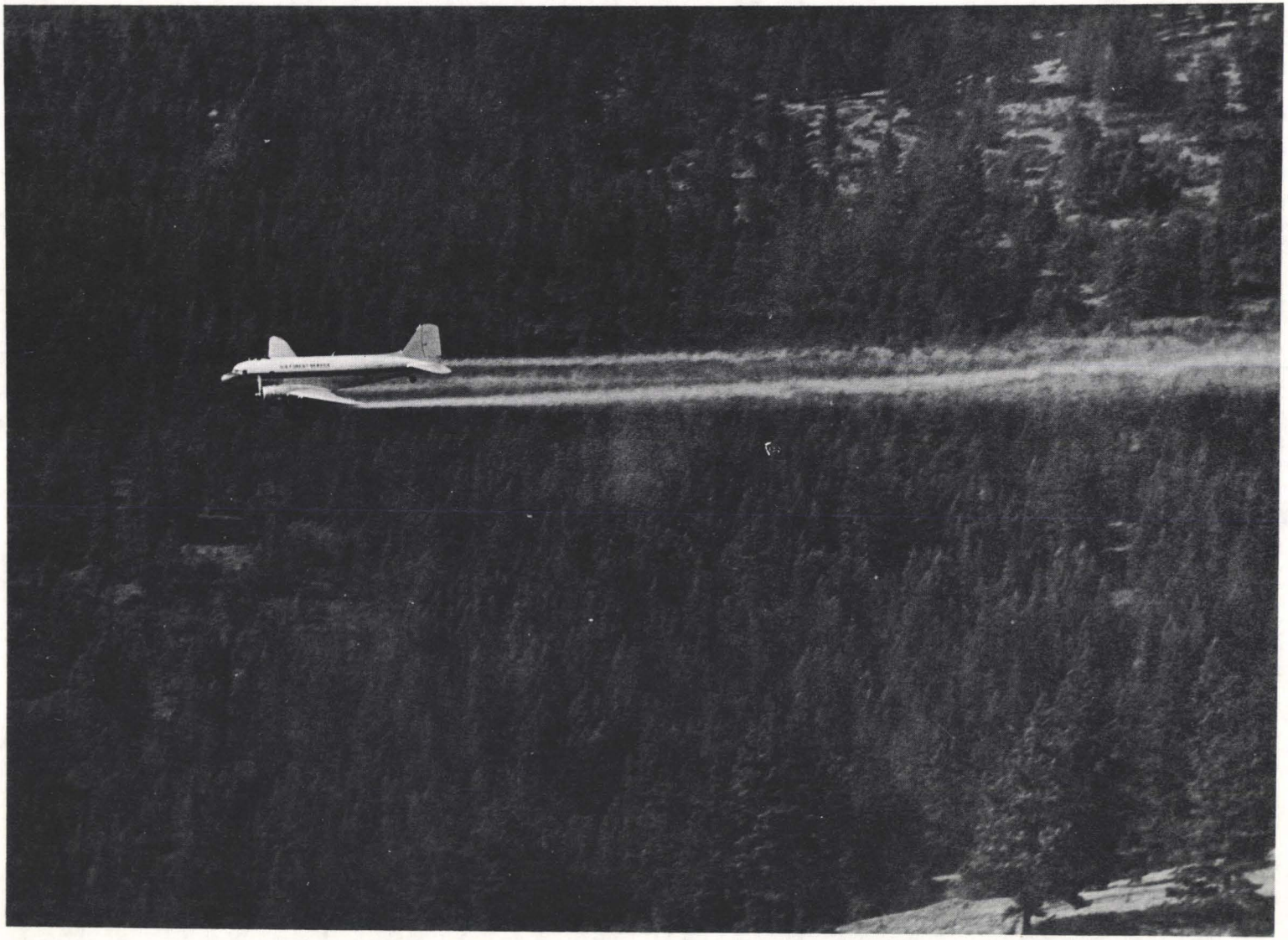
Percent maximum total flow	Solution flow rate, gpm	Insecticide fluid flow rate, gpm	Pints/acre of insecticide fluid
100	90.0	52.02	2.44
81	72.9	42.14	1.93
71	63.9	36.93	1.73
52	46.8	27.05	1.27
31	27.9	16.13	0.75
21	18.9	10.92	0.51

The application rate per acre was calculated from the following flight conditions which are considered average for spraying in mountainous terrain: (1) 6,000 foot density altitude, (2) 150 mph indicated airspeed, 168 mph true ground speed, and (3) 500 feet between flight paths.



C–47 SOLUTION SPRAY SYSTEM BOOM VALVE LOCATED IN THE FEED LINE FROM THE TANK TO THE BOOM FOR ON–OFF CONTROL OF THE SPRAY

FIGURE 39



C—47 SOLUTION SPRAY SYSTEM IN OPERATION

FIGURE 40

C-47 SOLUTION SPRAY SYSTEM IN OPERATION

FIGURE 41

The maximum flow rate is with 250 TX-26 nozzles which will dispense 90 gpm of solution of which 52.02 gpm is the insecticide carrier and 37.98 gpm is the atomizing fluid. The total capacity of the tank is 700 gallons. With an equal mixture by weight of the insecticide fluid and atomizing fluid, it will contain 404.6 gallons (57.8%) of Dowanol TPM and 295.4 gallons (42.2%) of Freon-12.

The Center now has two complete C-47 aerosol spray systems. Only one system is equipped with the selective flow rate boom. The drawings, however, reflect this latest change and only show the selective flow rate system.

C-47 AIRCRAFT PERFORMANCE AND SAFETY

Low level flying in mountainous terrain is hazardous even with an airplane performing at its peak efficiency. In the interest of safety it is therefore mandatory for the design engineer to carefully consider the effects of the spray system on the performance of the airplane.

In the design of the spray system for the C-47 airplane many factors such as the airplane gross weight, emergency tank discharge, location of the airplane's center of gravity, distribution of weight on the floor, the reinforcement of the cutouts in the fuselage, design of the tie-downs to withstand 9G crash landing loads, horsepower requirements under normal and emergency conditions and the parasite drag of the spray boom had to be evaluated.

All the factors except the latter two have been discussed in the previous sections. The horsepower required to carry the weight of the spray system and to overcome the parasite drag of the boom were first calculated and then reaffirmed by flight tests.

Even though the bifluid system had been abandoned, it was decided to measure the parasite drag of the boom for comparative data to determine what reduction in drag had been accomplished with the cleaner boom on the solution system. To measure the drag of the boom, the airplane was flown at the same gross weight, airspeed, and density altitude with and without the boom. The power settings were recorded in each case and the brake horsepower developed was taken from engine horsepower curves. It was found that the bifluid system with the double boom and large nozzles consumed 530 brake horsepower at a 150 mph indicated airspeed at a 5,000 foot density altitude. The solution system with the single boom consumed 260 brake horsepower at the same airspeed and density altitude.

From the preceding results it is quite apparent that the installation of equipment on the outside of an airplane will create drag forces that consume considerable horsepower. Therefore, the design engineer should exercise every care to keep these protuberances to a minimum and streamline them whenever possible. The bifluid system boom consumed much more

horsepower than the solution system boom because the frontal area was greater and the irregularities of the two booms and nozzles with the associated plumbing caused considerable turbulance. The solution system was more streamlined. These differences can be seen in Figures 24 and 36.

To determine the horsepower consumed by the weight of the insecticide solution, the tank was filled with 6,145 pounds of water and the airplane then flown level at a predetermined airspeed and density altitude. The water was released with the emergency tank discharge system and the power settings readjusted to maintain the previous airspeed at the same density altitude. From the difference between the power settings the brake horsepower required to carry the weight of the water was determined; it required 200 brake horsepower.

Of interest is the horsepower consumed by the spray boom as compared to the horsepower required to carry the weight of the fluid. This clearly shows how protuberances outside the airplane affect its performance to a much greater degree than adding weight. This is because the parasite drag coefficient for the boom may be as high as 1.28, whereas the increase in the wing drag coefficient resulting from the additional lift needed to carry the weight may be as low as 0.02.

The airplane equipped with the solution system with the tank empty and at a gross weight of 23,000 pounds was tested for single engine performance by throttling one engine to a power setting of zero thrust. It maintained level flight on one engine at an indicated airspeed of 85 mph at a 6,500 foot pressure altitude with a power setting of 2,150 rpm and 28" MAP (640 brake horsepower). With an increased power setting of 2,300 rpm and 36" MAP (830 brake horsepower), the airplane climbed with one engine at 240 feet per minute at an indicated airspeed of 80 mph from a 5,500 foot pressure altitude to a 6,700 foot pressure altitude. The outside air temperature was not recorded so the density altitude could not be determined. However, the flight was made early in the morning and a few days before the spray operation, so the results can be correlated with a fair degree of accuracy to conditions during a typical spray operation.

The maximum continuous brake horsepower of the engine is 1,050 which can be maintained up to a 7,000 foot density altitude. From this it is apparent that with only one engine in operation there is still a reserve of power. The idle engine set at a no thrust power setting is contributing considerable drag because of the rotating propeller. In an actual emergency the propeller would be feathered which would give much less drag resulting in more reserve horsepower.

The foregoing flight test information is not as complete and encompassing as would be desired. Because of a limited budget, accurate instrumentation could not be installed and the number of test flights were limited. The instruments in the airplane were used which can be considered accurate within 5% to 10%. However, the data does give good comparative values and a fair degree of accuracy on absolute values, which is accurate enough to give the pilot a good idea of the limitations of the airplane.

CONCLUSIONS AND RECOMMENDATIONS

The idea of producing small droplets that are transported and diffused by air currents is a very logical approach for applying insecticides because it reduces the quantity of insecticide needed and thus there is less contamination of the environment. This objective as well as others, are well explained by Dr. Arthur D. Moore in his article, "New Developments in Forest Insect Problems" (Appendix).

The aerosol system described in this report was never intended to be used in large volume applications that were used in the 1969 pilot tests in the Nezperce National Forest, Region 1. The high cost of the atomizing fluid makes the use of the system as an aerosol system in large volume applications prohibitive from the economic standpoint. On low volume applications the cost of the atomizing fluid is offset by an increased efficiency which will result in a cost per acre comparable to conventional high volume spraying methods. If the system is to be used for large volume applications, it should be used as a conventional system without the atomizing fluid.

Some of the past pilot tests did not produce the best results. From visual observations it appeared that the fine spray droplets did not descend into the trees but drifted outside the spray area. Because of this tendency of small droplets to move laterally and drift with air currents, it should be used as a means for moving the droplets into the trees and through the foliage. As studies of the use of natural air currents for this purpose have been very limited, it is suggested that a program be initiated to study air movements in mountainous terrain and determine how they can best be used to transport and diffuse insecticide sprays.

Questions have been raised about the evaporation rate of small droplets and as to whether they may evaporate completely before they reach the target. This again is a subject about which very little is known and should be studied more extensively. The U.S. Army Deseret Test Center at Dugway, Utah, has done some work in this area. They have found that pure liquids evaporate very rapidly but if nonvolatile impurities are added, the evaporation rate is greatly reduced.[7/] The insecticide could act as the impurity but if it is not in a large enough concentration to be effective, a dye could be added.

In the Province of New Brunswick, Canada, and in Maine, spraying is done in the late evening as well as in the morning. On all of our pilot spray

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7/ Technical Report, DTC-22. The evaporation of droplets of low volatility liquids, by William J. Romig and Duane E. Long, September 1969, Deseret Test Center, Dugway Proving Ground, Dugway, Utah.

projects the spraying has only been done in the morning. It would be worthwhile to investigate the results of spraying in the evening as the air currents generally are moving down the sides of the drainage (see Figure 2). It is very possible that a better distribution of the spray through the trees could be achieved.

As the public becomes more concerned over the continuing deterioration of our environment, the use of chemical insecticides will undoubtedly become an important controversial issue in the future. It would, therefore, behoove the Forest Service to continue the investigation of equipment for producing aerosol sprays and application methods for ultra low volume spraying.

APPENDIX A

18

UNITED STATES GOVERNMENT

Memorandum

Department of Agriculture - Forest Service
Berkeley, California 94701

TO : H. K. Harris, R-1

File No. 4500

FROM : Arthur D. Moore, Project Leader
Insecticide Evaluation Project

Date: Sept. 19, 1966

SUBJECT: Forest Insect Research

Your reference:

This memorandum is a followup to recent telephone discussions with Donn Cahill regarding our spray system needs for next summer's field testing program.

For the 1967 tests, we plan to use three different types of spray aircraft having the following general specifications:

Aircraft type	Minimum Spray speed	Flow rate	Minimum Load capacity
Helicopter	50 mph	4 gpm	75 gallons
Single-engine, fixed-wing	100 mph	15 gpm	200 gallons
Twin engine, fixed-wing	150 mph	45 gpm	1,000 gallons

We will use a dosage rate of one pint per acre.

Cahill mentioned that you are undertaking a new study to determine the most effective and economical type of aircraft to use for a particular spraying job. With this in mind, we would prefer that you select the particular aircraft make and model to use in developing the spray systems for the above three general aircraft types. You will have to recompute the flow rates if the spray speeds of the selected aircraft are much above those suggested as the desirable minimums.

Each spray system should produce drops that are all below 50 microns in size, with an MMD (mass median diameter) of 20 microns or less.

We will need to know the complete droplet spectra for each of the spray systems that you develop. This must include all droplets one micron and larger, preferably classified by five micron groups, e.g., 1-5, 6-10, 11-15, etc.

In testing the spray systems, use Dowanol DB, a Dow Chemical Co. product. It is available from Van Waters and Rogers, Spokane, Washington.

Contact Bill Zigmar, Phone 509-747-4183. It comes in two different containers, 10 gallon size at $0.77 per pound or 55 gallon size at $0.33 per pound. It weighs 7.92 pounds per gallon. The prices may vary slightly from those given because of freight charges, etc. The information was obtained from Dow Chemical in San Francisco.

The spray systems must be completed and ready for installation on project aircraft by June 1, 1967. In addition we will need to know by December 1, 1966, if there is any possibility that the systems cannot be designed, built, and ready for installation on the June 1 target date.

Please let us know if you will be able to develop the spray systems as outlined above. If you need any additional information, please contact us by telephone.

Robert L. Pierce
Lmd

Reprinted from Transactions of the Thirty-Fourth North American Wildlife and Natural Resources Conference, March 2, 3, 4, 5, 1969. Published by the Wildlife Management Institute, Wire Building, Washington, D. C. 20005

PESTICIDES—NEW FACTS, OLD PROBLEMS: A PANEL

NEW DEVELOPMENTS IN FOREST INSECT PROBLEMS

ARTHUR D. MOORE
Pacific Southwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Berkeley, California

Water and air pollution and other forms of deterioration in our environment are sources of considerable concern in forestry as in other fields. Efforts to minimize contamination by pesticides fall into two general categories: (1) attempts to find suitable alternatives to conventional insecticides, and (2) attempts to increase the efficiency and selectivity of the chemicals used.

The day is probably not far off when we will use pheromones, insect diseases, hormones, or other agents—instead of conventional insecticides—against some of our forest insect pests. Considerable progress has been made in isolating, identifying, and synthesizing the pheromones that attract bark beetles to their host trees under natural conditions (Wood *et al.*, 1968; Silverstein *et al.*, 1966). Studies are now being conducted to obtain the background information necessary for using pheromones for control (U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta., 1968a). The use of a virus disease for the control of Douglas-fir tussuck moth appears so close at the Pacific Northwest Station that work on conventional insecticides for this insect have largely been discontinued. Our laboratory studies have shown an insect hormone is effective against the spruce budworm at doses similar to those needed with the most toxic conventional insecticide.

We are studying the possibilities of getting the tree to work for us when it is necessary to get a chemical to an insect protected by plant tissue, e.g., the lodgepole needle miner (U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta., 1968b). In the not-too-distant future, we may be able to apply complex super molecules that readily penetrate the waxy cuticle of the foliage. From then on they are converted, by plant enzymes, to water-soluble molecules which move with the plant sugars and concentrate at the point of insect feeding activity. Hopefully, the active portion of the molecule will be a selective synthetic hormone or similar compound.

In the meantime, a major effort is being made by the U.S. Forest Service to increase the efficiency and selectivity of treatments with the more conventional-type chemicals.

The initial target in this endeavor at the Pacific Southwest Station

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continues to be the spruce budworm (U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta., 1965). To meet the immediate need of a treatment for this insect, it was necessary to turn to chemicals in production or experimental chemicals near the production stage and to the basic application equipment and procedures developed for DDT. Chemicals in or near production are not truly specific for the budworm, as their insecticidal activity was discovered in other insects. However, we believed that a selective treatment could be developed if three conditions were met: (1) if an insecticide could be found that would be more toxic to the budworm than to other organisms; (2) if it could be directed to the target insect with a higher degree of efficiency than to other organisms; and (3) if the parent insecticide and any active metabolites would be broken down in the forest ecosystem—thus, not build up in any plant or animal systems.

A carbamate insecticide, Zectran® (Dow Chemical Company) has shown a higher degree of selectivity for the budworm than any other chemical tested to date (U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta., 1967). It has a relatively high acute oral toxicity to mammals, but much lower dermal and chronic feeding toxicity—which are the main potential hazards in field use (Kenaga, 1966). Because it is much more toxic than DDT to the budworm, it can be used in much smaller quantities. The parent compound and main active metabolites are readily broken down by sunlight and in plant and animal systems (Abedel-Wahab *et al.*, 1966; Abdel-Wahab and Casida, 1967; Crosby *et al.*, 1965; Oonnithan and Casida, 1966; Oonnithan, 1966).

All studies to date (including studies on fish and wildlife) indicate that this material meets our first and third conditions to a higher degree than the other candidate compounds now available and that it can be used effectively and safely in the field. This then brought us to condition number 2—the task of directing the spray with greater efficiency to the target than to other organisms.

We found that one of the major problems involved in efficiently distributing a pesticide from the air to a forested area is penetration of the canopy. Any vegetation acts as a filtration system, but coniferous forests are especially efficient in filtering out the larger drops of a conventional aerial spray (Maksymiuk, 1963). Earlier work by other workers indicated that drops more than 100 microns in size penetrate vegetation only slightly or not at all. Most forest spraying is carried out with an atomization of 150 microns mass median diameter (Maksymiuk, 1964).[1] Thus, greater than 75 percent of the spray volume is in drop sizes too large to penetrate vegetative filtration

[1]50 percent of the spray volume being in drop sizes larger than 150 microns and 50 percent of the spray volume in drop sizes below 150 microns.

systems, especially those 100 feet in height. We reasoned that in a coniferous forest inhabited by budworm, the most efficient drop sizes might fall considerably below 100 microns. To test this possibility, we made a study to determine which drop sizes were actually getting to the budworm larvae. First, we had to develop a method for studying this variable. We found that very fine fluorescent particles suspended in the spray tended to distribute themselves according to spray volume in any given drop (Himel *et al.*, 1965). Thus, by counting the number of fluorescent particles left by a drop it was possible to obtain the approximate original size of that drop.

More than 1,000 spruce budworm larvae affected by spray in an experimental area were examined to determine the size and number of spray drops impinging on each insect (Himel and Moore, 1967). No evidence was found that a significant number of drops larger than 100 microns reached the target insects. Also, only a small number of droplets between 50 to 100 microns were found, and these on only 7 percent of the larvae. The study clearly indicated that only drops below 50 microns in diameter reached the budworm larvae with any high degree of efficiency. This finding is especially significant when we consider that about 95 percent of the spray applied to forests by conventional methods consists of droplets larger than 50 microns. This spray not only does not reach the target for which it is intended, but it is a major source of environmental contamination.

Next, we asked the U.S. Forest Service Equipment Development and Testing Center at Missoula, Montana, to develop a spray system that would eliminate the undesirable larger drop sizes. A system has now been developed that eliminates all drops above 120 microns in size. Freon is used to give additional breakup of the spray.

By means of aerially released oil smokes (less than 1 micron particle size) and by following fine aerial sprays with Lidar [laser radar equipment developed by the Aerophysics Group at the Stanford Research Institute (Anonymous, 1966)], we found that small airborne droplets reach the tree crowns and the budworm larvae through atmospheric transport and diffusion. Furthermore, diffusion and thermal and physical turbulence near the forest canopy may have been unrecognized allies in past operations.

Observations of the efficiency of different drop sizes pointed our attention to the importance of such bodies as setal hairs on the insect and silken webbing in determining the potential effectiveness of an aerial spray. These bodies are extremely efficient impingement devices for very small droplets.

Studies are also being conducted to determine ways to reduce the potential sting of some conventional type insecticides. For example,

addition of an N-acyl substituant to the carbamyl moiety of carbamates usually maintained biological activity on spruce budworm, but decreased the toxicity to mice to the point where a dosage of 1 gram per kilogram produced no visible effect. Thus, it is possible, by acetylation, to lower substantially the acute toxicity of these compounds to mammals without significantly altering their toxicity to spruce budworm.

In addition to the studies on control agents and their application, the Forest Service is emphasizing research on when and where to apply the treatments I have described, and how to integrate them with other applied or natural agents regulating the insect pest population.

In summary, an all-out effort is being made to substitute finesse for brute force in forest insect control.

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